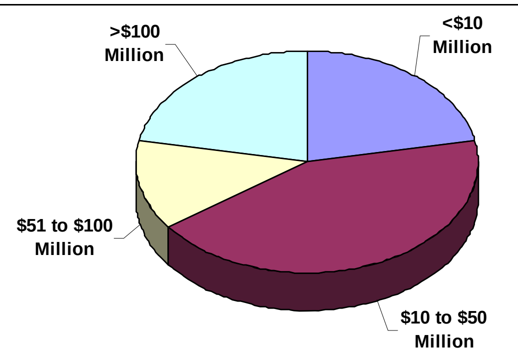
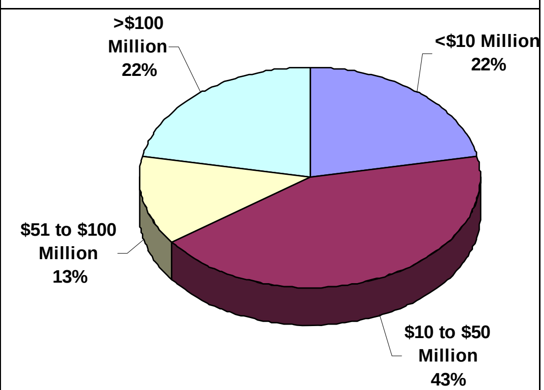
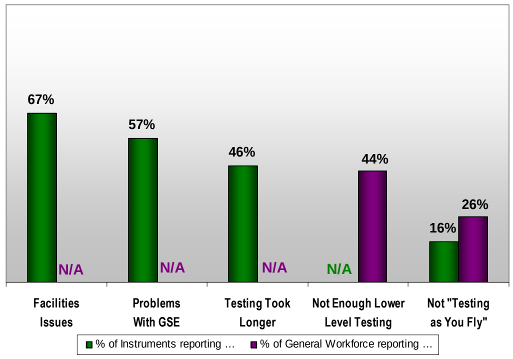
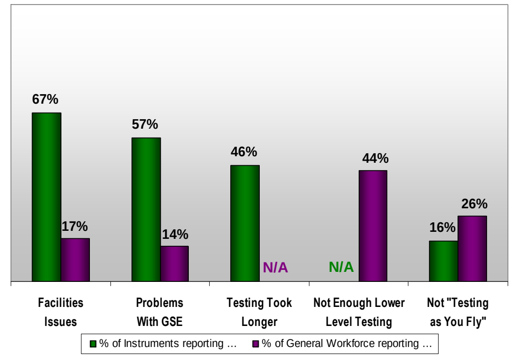
NASA Instrument Capability Study

Final Report

December 2008

Errata Sheet

Page	Reference	From	To
v	Tables, Line 6	Finding 5 Recommendation and Rationale	Finding 5 Recommendations and Rationale
vii	Paragraph 3, Line 10	… and a broad range of skill sets	… and a broad range of skills sets
x	Finding 2 Table, Column 1 Heading	Recommendations	Recommendation
xi	Finding 5	… any emerging or persisting issues.	… any emerging or persistent issues.
4	Paragraph 1, Item 2	… and/or university.	… and/or academia.
4	Figure 2.2.1-2		
9	Objective 3, Item 1	… (discussed in section 3.1.1).	… (discussed in sections 3.1.1 through 3.1.8).
14	Paragraph 4, Line 1	… were reported 1.3 times more often …	… were reported 1.3 and 1.2 times more often …
19	Paragraph 3	The top specific issues within the problem areas in figure 3.2.3-1 are presented below.	The top specific issues within the problem areas in figure 3.2.3-1 follow.
21	Paragraph 3, Line 3	… Although contract management problems are not reported by the instruments as often as other problems, challenged instruments are 2 times …	… Although contract management problems were not reported by the instruments as often as other problems, challenged instruments were 2 times …
23	Paragraph 2, Line 2	… in section 3.17, …	… in section 3.1.7, …
25	Paragraph 1, Line 13	… schedule delays of greater than or equal to 5 months.	… schedule delays of 5 months or more.
28	Paragraph 3, Line 1	… Langley Research Center directed …	… Langley Research Center directed a study of …
29	Paragraph 2, Line 9	… 3.3.1.3 and 3.3.1.4.	… 3.3.1.3 and 3.3.1.4, respectively.
30	Section 3.3.2.2 Heading	Optimistic Budget/Schedule Baselines and Impact	Optimistic Cost/Schedule Baselines and Impact

Page	Reference	From	To
45	Figure 3.3.5.2-1		
46	Paragraph 1, Line 2	… is workmanship or technical problems.	… is workmanship and/or technical problems.
46	Paragraph 3, Line 1	… aggressive schedule …	… aggressive schedule (45%) …
48	Paragraph 5, Line 7	… as discussed in section 4.3.5.3.	… as discussed in section 3.3.5.3.
48	Paragraph 6, Line 1	Another paper indicated that identified instrument …	Another paper identified instrument …
49	Table 3.3.6-1, SE-4, Supporting Information, Bullet 1	Lacked of resources to manage risks	Lack of resources to manage risks
50	Table 3.3.6-1, IM-4, Supporting Information bullet	Schedules and budgets not managed well as subsystem level	Schedules and budgets not managed well at subsystem level
52	Table 4-2, Column 1 Heading	Recommendations	Recommendation
54	Table 4-5 Title	Finding 5 Recommendation and Rationale	Finding 5 Recommendations and Rationale
54	Finding 5	… any emerging or persisting issues.	… any emerging or persistent issues.

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NASA Headquarters
Washington, DC

NASA Instrument Capability Study
Final Report

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PREFACE AND ACKNOWLEDGMENTS

This assessment is titled the National Aeronautics and Space Administration (NASA) Instrument Capability Study (NICS). The NICS report provides an evaluation of the state of instrument development within NASA, as well as organizations within the National Oceanic and Atmospheric Administration (NOAA) and the Department of Defense (DoD). The information contained herein is the product of fourteen months of hard work by the NICS team.

The NICS team included members from NASA Headquarters (HQ), Goddard Space Flight Center (GSFC), Jet Propulsion Laboratory (JPL), Johnson Space Center (JSC), NOAA, and DoD. The team also consulted, as necessary, with representatives of Johns Hopkins University/Applied Physics Lab (JHU/APL), The Aerospace Corporation, and support contractors to obtain individual viewpoints. The Review Board participants provided invaluable input throughout the assessment.

NASA acknowledges the contributions of representatives from government agencies and aerospace companies that supported this assessment by: responding to the NICS surveys, participating in the industry workshop, or providing feedback during focus groups. Their efforts were instrumental in the Study team's completion of this tri-agency assessment of instrument development capability.

A special thank you to those who supported this effort including: the OCE coordinators, Hal Bell and Adam West, for their leadership and guidance throughout the entire process; Pam Werner, from NASA Goddard Space Flight Center's (GSFC) Office of Chief Counsel, for her legal advice throughout the study; Elaine Slaugh, from GSFC, and Glenn Campbell and Tracee McCall, from NASA Headquarters, for setting up funding mechanisms for the Study; Bob Bartlett, from GSFC, as well as David Tratt and Jennifer Elfalan, from The Aerospace Corporation, for their independent research efforts; Elizabeth Clayton and Ana Wilson from the University of Maryland Conference Center (UMCC) and Tiffany Barr and her staff from the Wallops Flight Facility for helping with all the team workshop logistics; Tony Cazeau, from GSFC, for coordinating the Industry Workshop at the UMCC; Chris Durachka, Carlos Dutan, and Valerie Ward, from GSFC, for the overall software support, particularly the deployment of the web-based surveys and data collection; Alicia Gibbs, from GSFC, for her document production support; and Mary Pat Hrybik-Keith, from GSFC, for her graphics support.

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EXECUTIVE SUMMARY

Background and Objectives

In July 2007, the National Aeronautics and Space Administration (NASA) Office of the Chief Engineer (OCE) chartered the NASA Instrument Capability Study (NICS) team to determine whether NASA instrument developers are facing challenges that impact the capability to design and build quality instruments or whether there are flaws in the acquisition strategy evidenced by schedule delays, cost overruns, and increased technical risk via design deficiencies. The Study team was also chartered to determine if occurrences seen recently are coincident, but isolated cases or if there were generic issues causing such degradation. If the issues were found to be generic, the team was to offer solutions to recover such capability.

The NICS objectives were as follows:

1. Obtain macro-level understanding of problem areas within the instrument development processes (not root cause analysis)
2. Determine problem areas that impact primary success indicators (cost, schedule, and technical performance)
3. Determine specific issues within the identified problem areas that impact
    a. Instrument development processes
    b. Primary success indicators
4. Identify potential issues for higher risk or more complex instrument developments
5. Identify common, overarching themes spanning the instrument development processes
6. Recommend options for solutions that address Study themes

The Study Team

The NASA Goddard Space Flight Center (GSFC) led the Study and a cross-agency team was formed to implement it. Since science instruments are also developed by the National Oceanic and Atmospheric Administration (NOAA) and by the Department of Defense (DoD), the NASA OCE invited their participation in the Study to provide a broader perspective of instrument development. The team was made up entirely of civil servants and obtained support from NASA contractors in their areas of expertise. A Review Board was also formed to assist the team by providing the Board members' individual reactions, comments and suggestions to the team throughout the conduct of the Study.

Study Integrity and Confidentiality

A strict process was followed to ensure integrity and confidentiality across all Study elements. Survey respondent names were kept confidential and data was not attributed to respondents, instruments, or organizations. Raw survey data was accessed by limited NASA personnel and was redacted, aggregated, and plotted for analysis. These controlled data processing measures were followed and implemented by appropriate personnel to securely collect and process the data. Non-disclosure agreements were developed and signed by all non-NASA individuals who supported the Study team for data acquisition and analysis. Only government personnel participated in the formulation of recommendations, in compliance with the Federal Advisory Committee Act. The GSFC Office of Chief Counsel reviewed and approved the Study team processes and products.

Study Approach and Implementation

The NICS team developed a Study approach that included a top-level assessment of instrument development processes and success indicators (cost, schedule, and technical performance). The Study team implemented a comprehensive survey development process that resulted in two surveys: an Instrument Survey (IS) and a General Workforce Survey (GWS). In addition, a wide-ranging Independent Research (IR) effort was established to cross-reference with survey results and support formulation of recommendations. A layered approach was used in the data collection and processing phase. Measures were taken to ensure data accuracy and consistency. The data analysis approach involved a myriad of data tables and plots. The team utilized this data to identify correlations and derive higher-level themes.

The last step in the approach was to analyze all available data and to develop findings and recommendations. These recommendations were formed by government individuals only. Independent research was also reviewed to provide corroborative support for the recommendations. This process was reviewed and approved by the Study team, the Review Board, the GSFC Office of Chief Counsel, and the NASA OCE.

A total of 71 managers across 41 instruments completed the instrument survey. The instrument participation by sponsoring organization was: NASA (68.3%), DoD (19.5%), and NOAA (12.2%). The instruments spanned a broad budget, under $10M to over $100M, and schedule range, less than 3 years to over 6 years. The instruments were assessed at varying points of the development cycle, from Preliminary Design Review (PDR) through delivery. For the General Workforce Survey, 164 survey responses were received. NASA only requested civil servants and contractors, in the performance of their official responsibilities, to complete the survey. NASA informed industry and academia of the conduct of the Study and there were individuals from industry and academia who, on their own initiative, completed the survey. The team, of course, included their responses. The respondents represented multiple organizations and a broad range of skills sets. Finally, the Independent Research consisted of over 200 studies/reports, “lessons-learned”, mishap investigation reports, and media sources that resulted in approximately 1,000 entries relevant to the Study.

Study Results

Based upon the data from both surveys, the Study team was able to: (1) identify the top five cross-cutting problem areas and the most reported specific issues within these problem areas; (2) evaluate data across three additional areas critical to instrument development: complexity, risk, and cost/schedule performance; and (3) identify the overarching Study themes.

The top five problem areas most reported by the instruments and by the general workforce are shown in tables 1 and 2, respectively. Please note that Staffing and Schedule Management were common problems reported by both instruments and the general workforce.

Table 1. Top 5 Problem Areas as Reported by the Instruments

Area	% of Instruments Reporting Problems in this Area
Test Failures	95%
Staffing	93%
SMA Functional Areas	90%
Schedule Management	90%
Organizational Interface	88%

Table 2. Top 5 Problem Areas as Reported by the General Workforce

Area	% of General Workforce Reporting Problems in this Area
Acquisition	93%
Staffing	92%
Requirements Management	43%
Schedule Management	42%
Contract Management	36%

The Study team also defined populations for challenged versus successful, higher risk versus lower risk, and more complex versus less complex instrument developments. The tables below show the top 5 problems reported more often by challenged than successful (table 3), higher risk than lower risk (table 4), more complex than less complex (table 5) instruments. For example, as shown in table 3, 80% of the challenged instruments reported problems with risk management, which is 3.6 times more often than the successful instruments.

Table 3. Top 5 Problem Areas Reported More Often by the Challenged Instruments than the Successful Instruments

Area	% of Challenged Instruments Reporting Problems in this Area	% of Successful Instruments Reporting Problems in this Area
Risk Management	80%	22%
Acquisition	95%	44%
Contract Management	44%	22%
Budget Management	90%	67%
Requirements Management	85%	67%

Table 4. Top 5 Problem Areas Reported More Often by the Higher Risk Instruments than the Lower Risk Instruments

Area	% of Higher Risk Instruments Reporting Problems in this Area	% of Lower Risk Instruments Reporting Problems in this Area
Contract Management	46%	13%
Risk Management	76%	44%
Acquisition	100%	62%
Budget Management	88%	56%
Staffing	100%	81%

Table 5. Top 5 Problem Areas Reported More Often by the More Complex Instruments than the Less Complex Instruments

Area	% of More Complex Instruments Reporting Problems in this Area	% of Less Complex Instruments Reporting Problems in this Area
Configuration Management	76%	44%
Risk Management	76%	44%
Budget Management	88%	56%
Organizational Interface	96%	75%
Acquisition	92%	75%

Upon analyzing the data in tables 1-5 above, the Study team identified five overarching themes: staffing, acquisition, systems engineering, instrument management, and testing issues. Common issues or threads, and their impacts, were examined within each of the themes and these threads were then evaluated across all of the themes to develop the overall Study findings and recommendations.

Findings and Recommendations

While performing a systematic review and assessment of 41 instruments across NASA, NOAA, and DoD, the NASA Instrument Capability Study team found that there were both overarching factors, as well as process issues that are impacting instrument development. A correlation was made between the issues identified and an increased likelihood of schedule delays, cost overruns, and technical problems. The Study team's analysis has been rolled up into the following findings:

Finding 1: Instrument developments lack the resources and authority to successfully manage to cost and schedule requirements.

Finding 1 Recommendations and Rationale

Recommendation	Rationale
1. Implement changes to policy to define and elevate instrument management requirements and authorities in a manner similar to project-level management. 2. Assign NASA instrument managers full authority and responsibility to manage their cost and schedule reserves and hold them accountable. 3. Require 30% to 50% cost reserves for instrument developments (>$10M) to account for the fact that most instrument developments are highly complex, single builds. 4. Require 1½ to 2 months per year of schedule reserve for instrument developments (>$10M). 5. Require dedicated level of support staff (configuration management, schedule management, risk management and budget management) for instrument developments (>$10M).	Instrument developments are uniquely complex, often one-of-a-kind, and, as such, require a higher level of visibility, authority, and support than normal spacecraft subsystems. Transition of authority to the lower levels is necessary to permit informed management and mitigation of risks before they turn into more expensive problems. The typical rule of thumb of 25% cost reserve and 1 month per year schedule reserve does not appear to be sufficient for instrument developments. This is corroborated by the data which indicated that ~70% of the instruments reported 25% or more cost overruns and ~60% of the instruments reported schedule delays of 5 months or more.

Finding 2: **Instrument developments are lacking the critical skills, expertise, or leadership to successfully implement these unique (one-of-a-kind), high technology developments.**

Finding 2 Recommendations and Rationale

Recommendation	Rationale
1. Expedite the planned enhancement of the NASA Engineering Network People, Organization, Project, Skills (POPS) expertise locator to enable instruments to address critical skills shortages by drawing upon personnel from other NASA centers. 2. Add capability to the POPS locator to include data sources external to the NASA workforce. 3. Require the addition of a deputy instrument manager position (similar to a deputy project manager), for instrument developments with a budget >$10M.	Expediting the POPS expertise locator enhancement will allow instrument projects to locate critical skills in the near term mitigating staffing issues, which is one of the top five problems reported in this Study. POPS allows instruments to draw from a wider pool of potential expertise. Given the complexity and scope of instrument developments, the addition of a deputy instrument manager position is warranted. This position creates a mechanism for transfer of corporate knowledge, training and mentoring, and provides critical support to the instrument manager. Finally, it ensures continuity, should leadership transitions occur.

Finding 3: **There are significant process problems in the area of requirements formulation, reviews, and management.**

Finding 3 Recommendations and Rationale

Recommendation	Rationale
1. Require NASA instrument team leadership to take requirements formulation/management training, e.g., "Requirements Development and Management (APPEL-REQ)", prior to requirements development. 2. Require instrument teams to conduct Peer Reviews of requirements (for each instrument subsystem), in preparation for instrument SRRs. 3. Require draft mission Level 1 and 2 technical requirements to be controlled and provided to instrument managers prior to the instrument SRR. Also, notify instrument managers of any changes to the draft requirements so that impact assessments can be performed.	In order to fix the requirements problems reported in the Study, a wide range of recommendations should be implemented. These recommendations include a greater emphasis on training to provide instrument teams a better understanding of how to formulate and manage requirements. The recommendations also provide an improved requirements review process to account for the fact that instrument SRRs occur much earlier than mission SRRs which often leads to requirements changes, as well as traceability issues. Finally, a recommendation is added to provide instruments with top level requirements early in formulation to allow for a more thorough requirements development and management process.

Finding 4: **Unrealistic caps, overly optimistic estimating, and externally directed changes correspond to a significant increase in the likelihood of overrunning cost and schedule.**

Finding 4 Recommendations and Rationale

Recommendation	Rationale
1. Develop an Agency-level historical cost and schedule database of instruments to provide information that would allow for higher fidelity cost caps.	The costing database will be useful in: establishing higher fidelity cost caps; evaluating government and contractor instrument proposals; and assessing progress during implementation. Furthermore, a data exchange between NASA, NOAA, and DoD on instrument development cost data would allow for a more thorough data set.
2. Review cost credibility evaluation and scoring criteria for accuracy and flow-down to the proposal selection process (for use by Technical Management and Cost (TMC) or project Source Evaluation Board (SEB)).	Improved cost credibility criteria support a more robust and thorough source selection.
3. Establish a Peer Review prior to PDR for instruments >$10M to assess budget and schedule baseline credibility and increase the emphasis on cost and schedule assessment at PDR.	Adding a budget and schedule baseline credibility Peer Review prior to PDR will increase confidence going in to the Confirmation Review.
4. Ensure that instrument managers are made aware of externally driven changes in a timely manner and afforded the opportunity to discuss any impacts prior to implementation of changes.	Early communication of externally driven changes (e.g., budget or schedule changes) down to the instrument level minimizes the impact to the instrument development.

Note: The NICS team did not develop a recommendation for cost estimating problems since this issue is currently being addressed by a multi-Agency team (The Space Systems Cost Analysis Group, co-chaired by NASA). This group is sponsoring a Baseline Realism Team.

Finding 5: **NASA needs a method to continue answering basic questions pertaining to the instrument development process to identify any emerging or persistent issues.**

Finding 5 Recommendations and Rationale

Recommendation	Rationale
1. Require *all* instrument managers to take the survey upon delivery of their instrument. 2. Maintain survey results in a historical database.	The aggregated data could provide the Agency information regarding trends, persistent issues, and emerging issues.

Concluding Remarks

While the focus of this study was to determine whether or not there are global issues impacting instrument development, the Study team found areas where no corrective action is needed. Examples of this include: S&MA requirements, which were reported as appropriate; and informal reviews, which were viewed favorably by the survey respondents. The NASA Instrument Capability Study has established a foundation for objective instrument development analysis. A strict process was followed to ensure integrity and confidentiality across all Study elements. Quantitative data has been collected and analyzed, which indicates that the instrument developers are indeed facing challenges that impact the capability to design and build quality instruments. These challenges focus on lack of resources and authority to successfully manage these instruments, lack of critical skills or expertise to implement these one-of-a-kind developments, significant problems in the area of requirements (formulation, reviews, and management), and issues with unrealistic caps, overly optimistic/unrealistic cost estimating, and externally directed changes impacting cost and schedule. The Study team recommended top-level changes in the way the Agency views and implements instrument development. The Study team also recommended improvements to key instrument development processes, such as project staffing and acquisition. The recommendations to address the Study findings should be implemented as soon as possible, with the highest level of priority. Since the NICS team only scratched the surface of problems impacting the capability to develop instruments, recommendations for continued data analysis were also provided.

Finally, the team recommends future steps to provide NASA a mechanism to work with other agencies to improve instrument development capability. To this end, the team recommends that the Agency establishes a strategic instrument capability alliance dedicated to improving the capability to design and build quality instruments within cost and schedule constraints. The alliance would provide for the following:

1. A collaborative framework for improving instrument development processes;
2. Participation from NASA, NOAA, DoD, industry, and academia;
3. Support of the implementation of Study recommendations;
4. Revision of the existing Study surveys based upon lessons learned; and
5. Development and maintenance of a tri-Agency instrument survey data repository.

1 INTRODUCTION

1.1 Study Background and Purpose

Over the last 50 years, the National Aeronautics and Space Administration (NASA) has been very successful designing and building instruments for Earth and Space science missions. However, recently, some NASA projects have had difficulties developing science instruments. In some cases, this appears due to challenges in the design process. In other cases, this appears due to difficulty in implementing the design to achieve the objectives. This situation has affected projects across the NASA mission directorates, thus a comprehensive cross-cutting study was chartered by the NASA Office of the Chief Engineer (OCE) to evaluate instrument development capability across the Agency.

The NASA OCE chartered the NASA Instrument Capability Study (NICS) team to determine whether NASA instrument developers are facing challenges that impact the capability to design and build quality instruments or whether there are flaws in the acquisition strategy evidenced by schedule delays, cost overruns, and increased technical risk via design deficiencies. The Study team was also chartered to determine if occurrences seen recently are coincident, but isolated cases or if there were generic issues causing such degradation. If the issues were found to be generic, the team was to offer solutions to recover such capability.

The NICS objectives are as follows:

1. Obtain macro-level understanding of problem areas within the instrument development processes (not root cause analysis);
2. Determine problem areas that impact primary success indicators (cost, schedule, and technical performance);
3. Determine specific issues within the identified problem areas that impact;
    a. Instrument development processes; and
    b. Primary success indicators
4. Identify potential issues for higher risk or more complex instrument developments;
5. Identify common, overarching themes spanning the instrument development processes; and
6. Recommend options for solutions that address Study themes.

1.2 Study Team

Since science instruments are also developed by the National Oceanic and Atmospheric Administration (NOAA) and the Department of Defense (DoD), the NASA OCE invited their participation in the Study to provide a broader perspective of instrument development. A Review Board was also formed to assist the team by providing the Board members' individual reactions, comments and suggestions to the team throughout the Study. The NICS team structure is depicted in figure 1.2-1.

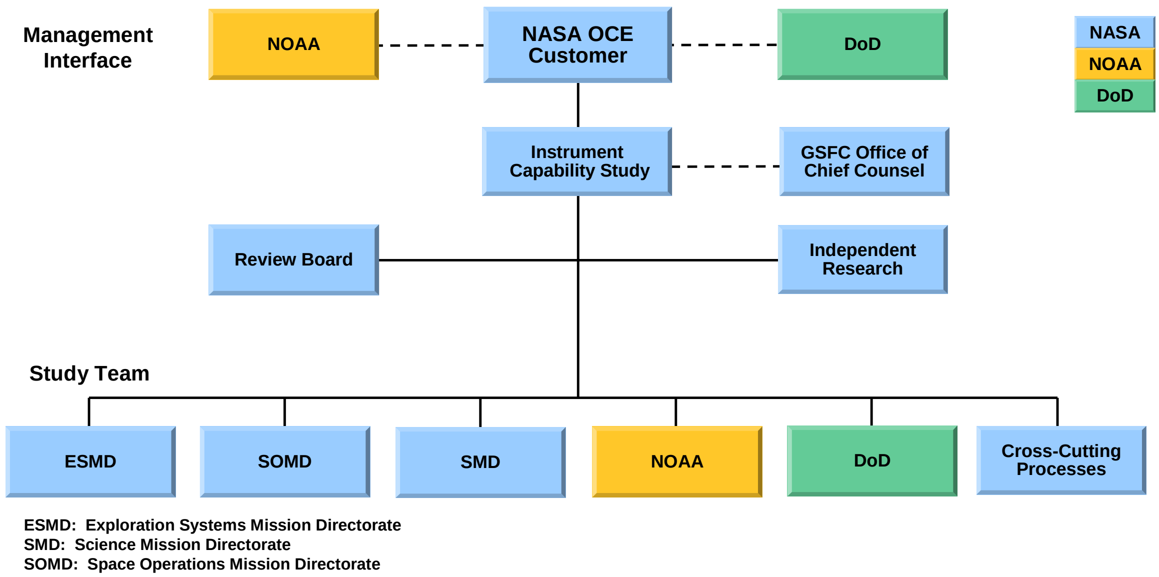

Figure 1.2-1. NICS Team Structure

1.3 Study Integrity and Confidentiality

A strict process was followed to ensure integrity and confidentiality across all Study elements. Survey respondent names were kept confidential and data was not attributed to respondents, instruments, or organizations. Raw survey data was accessed by NASA personnel only and was redacted prior to being aggregated and plotted for analysis. Survey data was also cross-referenced with independent research data, which was also redacted. These controlled data processing measures were followed and implemented by appropriate personnel to securely collect and process the data. Non-disclosure agreements were developed and signed by all non-NASA individuals who supported the Study team for data acquisition and analysis. Only government personnel participated in the formulation of recommendations, in compliance with the Federal Advisory Committee Act. The GSFC Office of Chief Counsel reviewed and approved the Study team processes and products.

2 STUDY APPROACH AND IMPLEMENTATION

The Study team developed a Study approach that included a top-level assessment of instrument development processes and success indicators (cost, schedule, and technical performance). The Study team implemented a comprehensive survey development process that resulted in two surveys: an Instrument Survey (IS) and a General Workforce Survey (GWS). This process was reviewed and approved by the Study team, the Review Board, and the NASA OCE. In addition, a wide-ranging Independent Research (IR) effort was established to cross-reference with survey results and support formulation of recommendations. A layered approach was used in the data collection and processing phase. Measures were taken to securely collect and process the survey data and to ensure data accuracy and consistency. The data analysis approach involved generating a myriad of data tables and plots. The team utilized this data to identify correlations and derive higher level themes. The last step in the approach was to analyze all available data and develop findings and recommendations.

2.1 Study Tools

The survey development process is shown in figure 2.1-1. NASA GSFC instrument managers and systems engineers and the Study team identified numerous issues encountered during instrument development. The Study team then identified eight cross-cutting processes and sub-categories, which were based on their criticality to instrument development. Next, the survey questions were then derived from the processes and sub-categories. Through multiple iterations, the Study team was able to develop the IS, as one of three tools to be utilized to collect data. The team also implemented a GWS and conducted IR to enable a comprehensive analysis of instrument development capability. The implementation of the three Study tools, IS, GWS, and IR, is discussed in the following subsections.

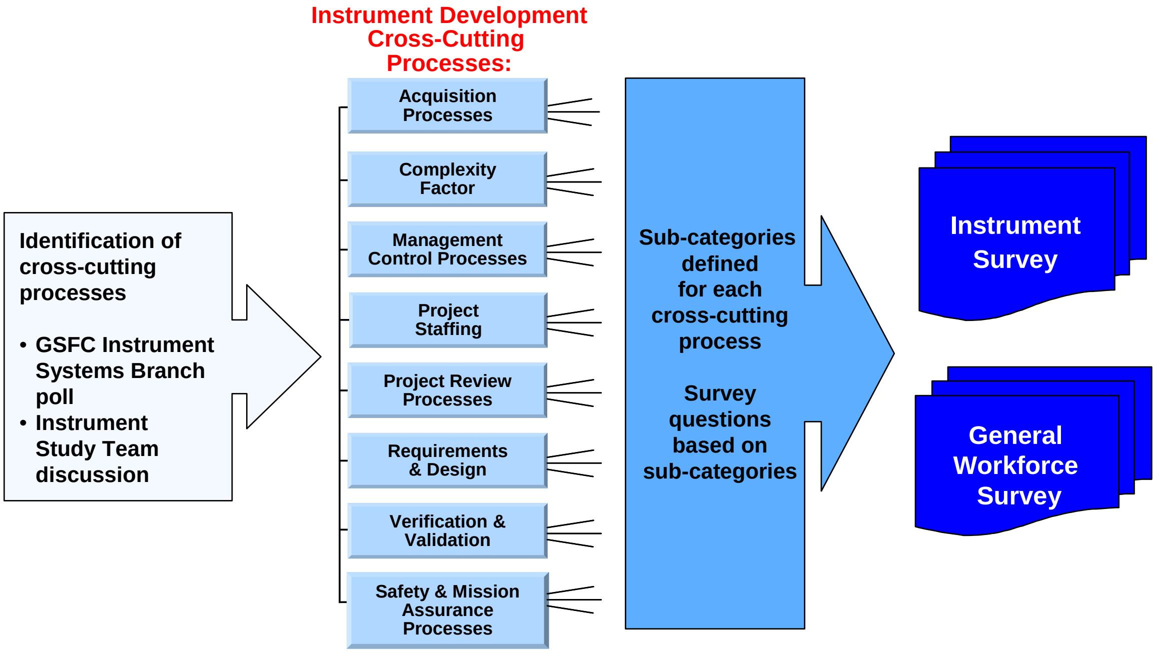

Figure 2.1-1. Survey Development Process

2.1.1 Instrument Survey

The Instrument Survey (IS) involved a top-down approach geared towards instrument/project managers and sought instrument development insight. Survey respondents were asked to participate based on the following criteria:

1. Instruments with a near-term time horizon (i.e., design through delivery, within approximately 5 years); and
2. Instruments from across government, industry, and/or academia.

Neither budget, schedule, technical parameters, nor instrument type were used as criteria for instrument participation.

The IS consisted of 49 questions and 10 background questions relating to the respondent's specific instrument development. A goal of the IS was to maximize acquired information while minimizing the burden to the respondent. The survey was implemented as a web-tool and was designed to be completed in approximately 1 hour. To encourage complete honesty with no fear of retribution or attribution, respondents were informed that their responses would be kept confidential. A total of 71 managers across 41 instruments completed the IS. Figure 2.1.1-1 shows the number of instruments surveyed within NASA, NOAA, and DoD.

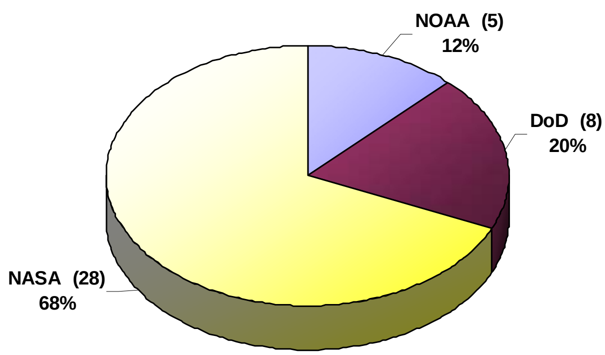

Figure 2.1.1-1. Instrument Participation by Sponsoring Organization

The instruments spanned a broad budget and schedule range as depicted in figure 2.1.1-2. Approximately 65% of the instruments had a budget of less than or equal to $50M at contract award or proposal selection. In addition, approximately 80% of the instruments had a schedule duration of less than or equal to 4 years at contract award or proposal selection.

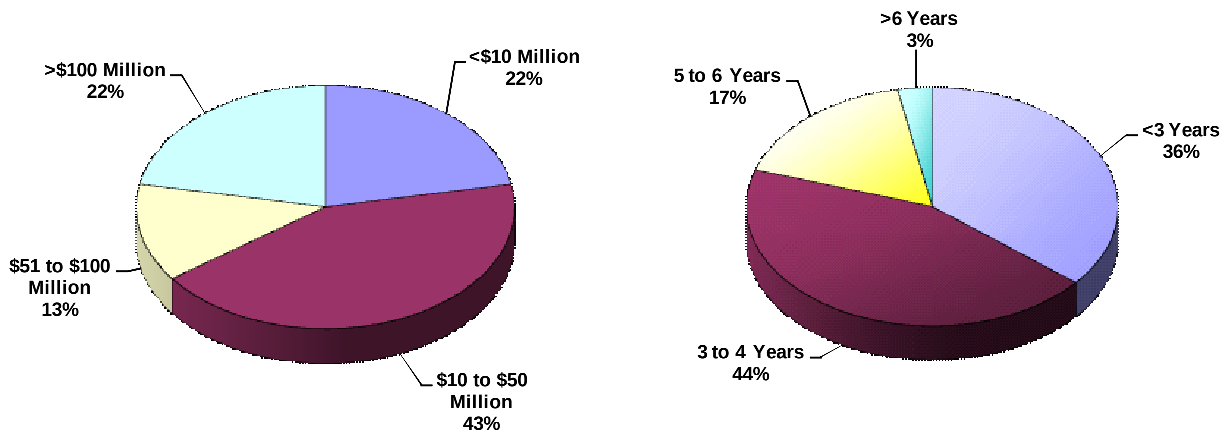

Figure 2.1.1-2. Instrument Budget and Schedule Duration

The instruments were assessed at varying points of the development cycle, from System Requirements Review (SRR) through delivery (see figure 2.1.1-3). Most of the instruments were in Phases A through D at the time of the survey.

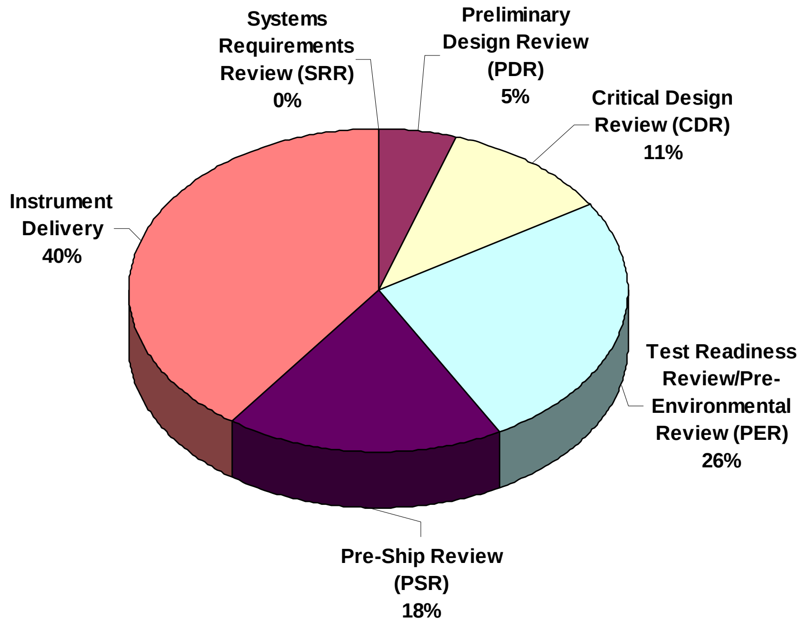

Figure 2.1.1-3. Most Recent Review Completed

2.1.2 General Workforce Survey

The General Workforce Survey (GWS) involved a bottoms-up approach geared toward instrument development team members and sought floor-level insight from engineers, scientists, quality assurance personnel, technicians, and safety personnel. The GWS polled the general experience of the respondents and was not tied to any particular instrument development. While NASA only requested the participation of government employees and contractors, in the performance of their contractual duties, the survey was also available to laboratories, universities, federally funded research and development centers (FFRDCs), and the aerospace industry. The respondents represented multiple organizations and a broad skill set.

The GWS consisted of three broad areas focused on the difficulty in developing instruments and referenced the same cross-cutting processes as the IS. The questions were easy to answer and could be completed in about 20 minutes, via a web based tool. For the GWS, 164 survey responses were received. Figure 2.1.2-1 shows the workforce participation across U.S. and foreign government, industry, and academia. The respondents represented multiple organizations and a broad range of skills set (see figure 2.1.2-2).

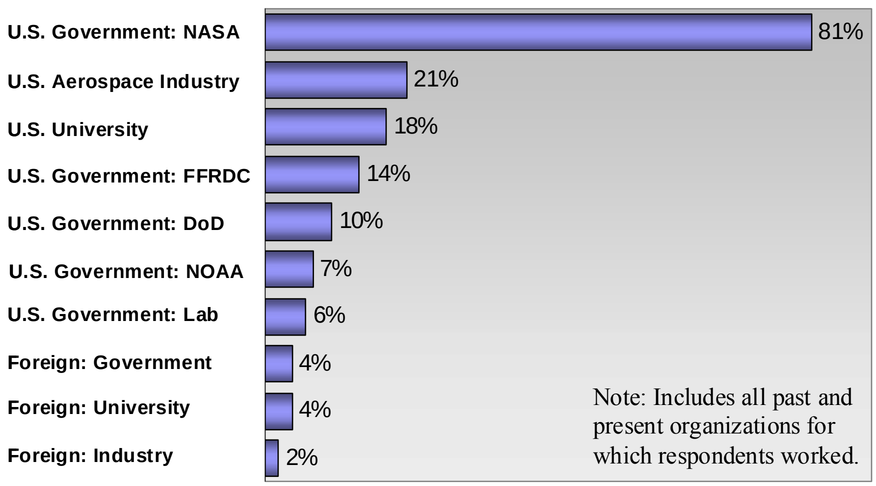

Figure 2.1.2-1. General Workforce Participation by Organization

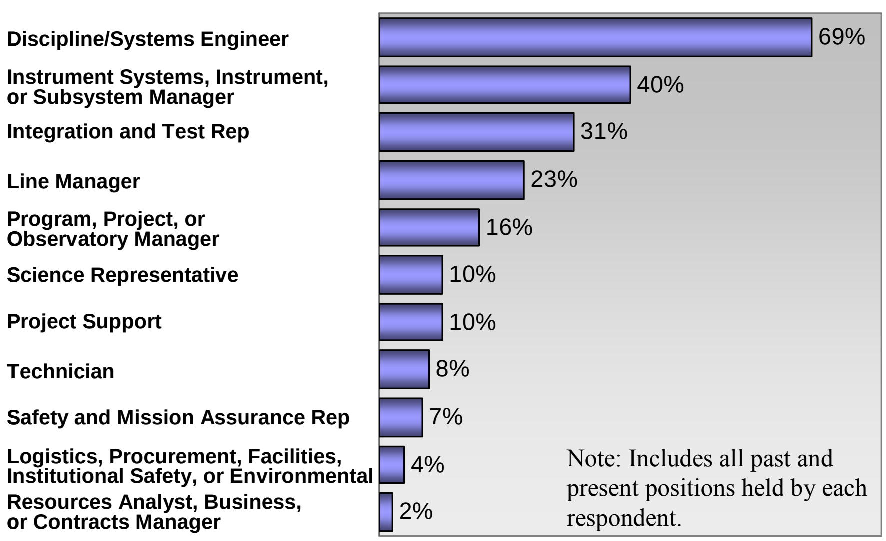

Figure 2.1.2-2. General Workforce Participation by Role

2.1.3 Independent Research

In addition to the two surveys, the Study team performed independent research to acquire supporting information on instrument development issues. This valuable research highlighted numerous issues that corroborated survey data and supported the development of recommendations for this Study.

The independent research data-mining process involved:

1. Searching for similar studies and reports that were developed by NASA, NOAA, DoD, or the aerospace industry to gain an understanding of past efforts that might have relevance to this Study;
2. Reviewing NASA's lessons-learned database;
3. Reviewing NASA's mishap investigation board reports; and
4. Researching public media to gather information on instrument development problems.

More than 200 relevant sources were acquired and reviewed for this Study. This resulted in more than 1,000 entries, which were entered into a comprehensive database to:

1. Link each entry to a cross-cutting process and sub-category;
2. Link each entry to a primary success indicator (cost, schedule, or technical performance); and
3. Link each entry to a reference (i.e., document name and number, source type, author, date, page number, and so on).

The database was designed to quickly generate different kinds of reports (e.g., cross-cutting process, sub-category, primary success indicator, particular type of reference source, or simple text [keyword] search).

2.2 Survey Data Collection, Processing, and Control

A layered approach was used to ensure data integrity throughout the Study process, particularly in the data collection and processing phase. The IS and GWS were implemented via a web tool. Controlled data-processing measures were developed and the appropriate personnel were identified to securely collect, process, and control the survey data. Figure 2.2-1 illustrates the survey data collection and processing flow. Once the raw data was received, it was redacted, then aggregated, and plotted for analysis. Finally, the survey results were cross-referenced with the IR.

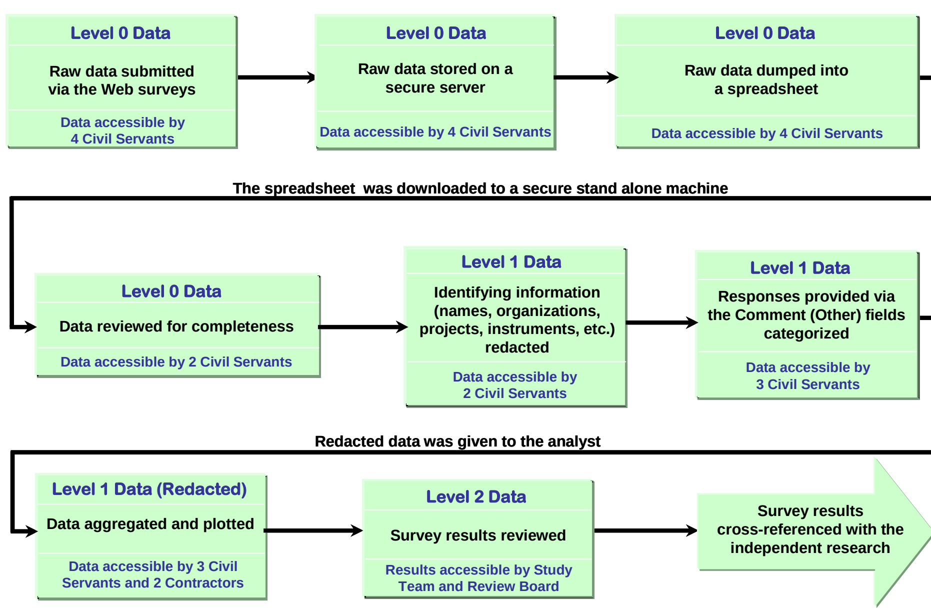

Figure 2.2-1. Survey Data Collection and Processing Flow

The independent research process flow is shown in figure 2.2-2. Once the sources were identified, pertinent information was extracted and mapped to the cross-cutting processes and primary success indicators, then entered into the database. Finally, the IR results were cross-referenced with results from both surveys. The research results were used to help formulate recommendations.

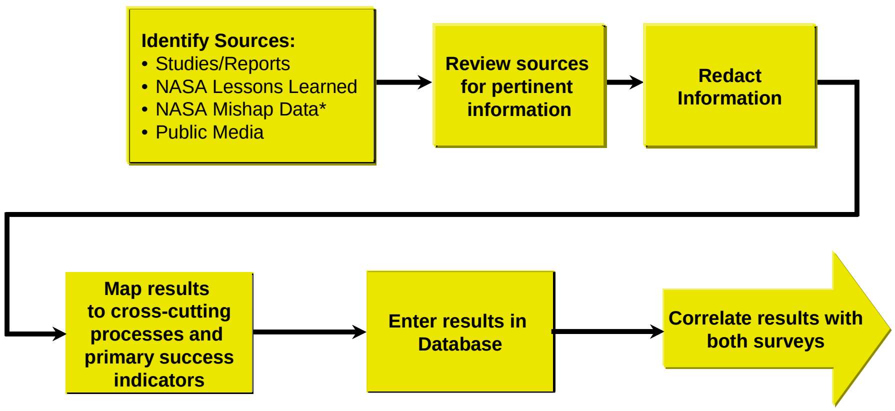

Figure 2.2-2. Independent Research Data Collection and Processing Flow

2.3 Data Analysis Approach

The Study team generated a full spectrum of survey plots to identify and analyze potential problems within instrument development. As part of the data analysis approach, the Study team developed a process to ensure data accuracy and consistency. The process consisted of the following:

1. Using embedded formulas to verify tables and calculations;
2. Auditing the plots/tables against raw data;
3. Auditing the independent research data for accuracy and completeness; and
4. Utilization of three independent tools (spreadsheet and a mathematical programming tool) for independent verification of data.

The Study team analyzed the data in layers, progressively refining and sorting correlations. This approach culminated in the Study findings, as depicted in figure 2.3-1.

Preliminary data analysis involved a broad brush approach to globally identify relationships and correlations. This led to the development of preliminary findings. An industry workshop was conducted to share the Study plan and preliminary findings with the aerospace industry and to request their feedback.

During the intermediate data analysis, the team identified problem areas and associated specific issues that had the highest frequency of reported occurrences and strongest correlations to the success indicators (cost, schedule, and technical performance). Additionally, the team defined populations for risk and complexity and plotted these populations across all survey questions.

During the final data analysis, the Study team looked across the previously identified problem areas/specific issues and correlations to identify overarching themes. The Study team then evaluated data within each theme to determine common threads. Finally, the Study team assessed the common threads across all themes to develop the Study findings, which are the focus of the recommendations.

Focus groups that included NASA, NOAA, and DoD managers and systems engineers were conducted to obtain feedback for consideration in the formulation of findings and recommendations. Recommendations were then formed by a government-only subset of the team. Independent research was also reviewed to provide corroborative support for the recommendations. The findings underwent a layered review by the Study team, the Study Review Board, and the NASA OCE.

The Study team objectives and associated products are referenced below:

Objective 1: Obtain macro-level understanding of problem areas within the instrument development processes (not root cause analysis).

1. Shown as the top 5 problem areas most-reported by respondents (discussed in section 3.1).

Objective 2: Determine problem areas that impact primary success indicators (cost, schedule, and technical performance).

1. Shown as the problem areas more often reported by the challenged instruments than the successful instruments (discussed in section 3.2.3).

Objective 3: Determine specific issues within the identified problem areas that impact instrument development processes and primary success indicators.

1. Shown as the most-reported specific issues within the top 5 problem areas in Objective 1 above (discussed in sections 3.1.1 through 3.1.8).
2. Shown as the specific issues with the highest differential within the problem areas identified in Objective 2 above (discussed in sections 3.2.3.1 through 3.2.3.5).

Objective 4: Identify potential issues for higher risk or more complex instrument developments.

1. Shown as problems more likely encountered by more complex/higher risk than by less complex/lower risk developments (discussed in sections 3.2.1.1 and 3.2.2.1).

Objective 5: Identify common, overarching themes spanning the instrument development processes.

1. Shown as issues and their impact to success indicators (discussed in section 3.3).

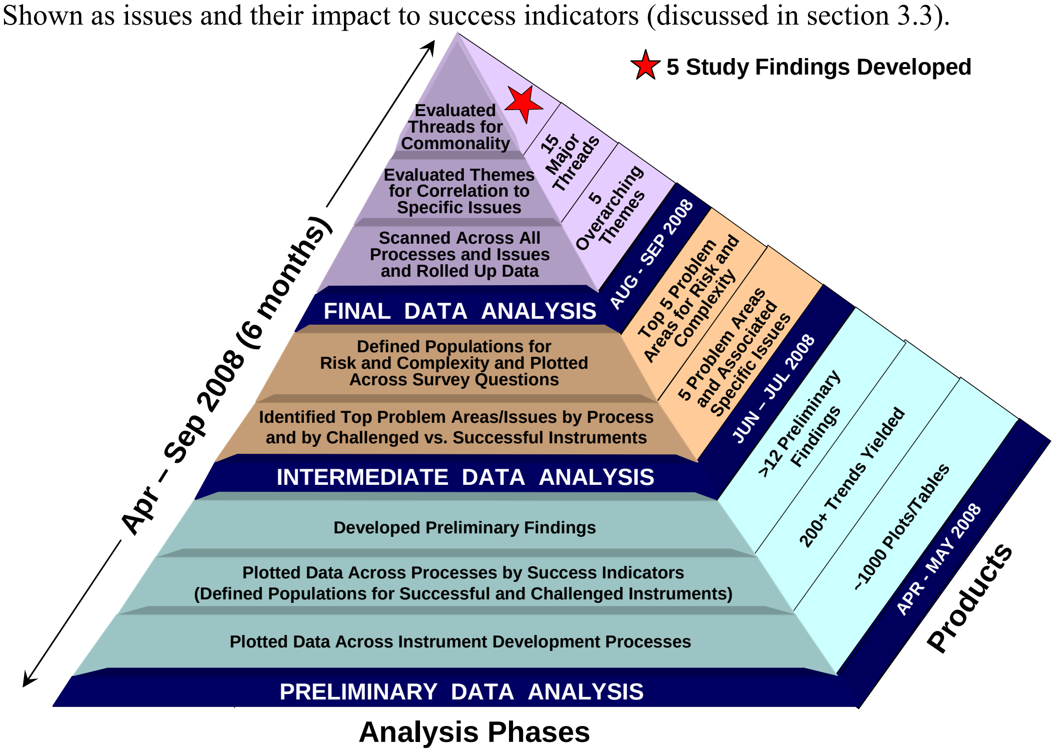

Figure 2.3-1. Study Data Analysis Phases and Products

3 STUDY RESULTS

The NICS data was initially analyzed across the instrument development processes used to formulate the instrument and general workforce surveys. Section 3.1 summarizes the results of that analysis depicting the top five cross-cutting problem areas followed by the most reported specific issues within these problem areas. Section 3.2 shows an evaluation of the data across three additional areas critical to instrument development: complexity, risk, and cost/schedule performance. Finally, in section 3.3, overarching Study themes are provided which represent an evaluation across the entire Study data set. These themes are the basis for the findings referenced in section 4.

3.1 Top Five Cross-Cutting Problem Areas

As shown in figure 3.1-1, the top problem area reported by instruments was test failures, whereas the top problem area for the general workforce was acquisition. It is worth noting that both the instruments and general workforce reported staffing and schedule management as top problem areas.

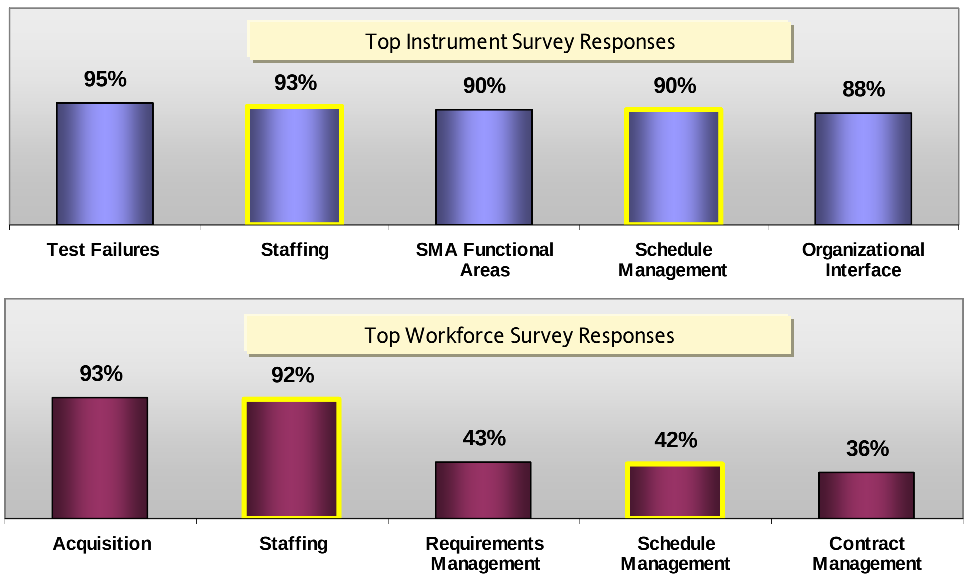

Figure 3.1-1. Top Five Cross-Cutting Problem Areas as Reported by Instruments and General Workforce

The following sections provide a summary of the most reported specific issues within each problem area referenced in figure 3.1-1. Data from the instrument survey, general workforce survey, and independent research are utilized to provide an aggregate view of the problem areas.

3.1.1 Test Failures

The top two contributors to test failures, as reported by the instruments were:

1. Workmanship and/or technical problems (82%); and
2. Human error (50%).

These are both human interface issues. Aggressive schedule was also reported often (45%). As problems are identified through testing, they have to be resolved successfully and quickly to avoid affecting the integration effort at the next level of the system or spacecraft. Instrument test teams often work under pressure, so it is not surprising that human interface problems and aggressive schedules were cited as contributors to test failures.

3.1.2 Staffing (Common to Both Surveys)

The top two issues in the staffing problem area are related to expertise:

1. Critical knowledge limited to a few individuals as reported by the instruments (68%); and
2. Difficulty in finding expertise as reported by both the instruments (61%) and the general workforce (64%).

In addition, 50% of the instruments and 59% of the general workforce reported personnel supporting multiple projects as an issue. These issues highlight a shortage of skilled individuals to meet growing demands. This is corroborated by the independent research which stated that the pipeline of science and engineering talent is shrinking at the same time that the demand is increasing in the private sector.[1, 3, 21] Another example from the independent research is found from a Mishap Investigation Board (MIB) assessment of eight missions. The MIB found that the root causes and contributing factors of mission mishaps were organized into recurring areas or themes, and inadequate training and experience was one of these themes. Specifically, for one of the missions, a contributory cause to the finding that the spacecraft initially failed to achieve its pointing requirements was the lack of adequate, relevant experience by some of the guidance and control personnel. The MIB identified the lack of training and experience of the design team as one of the root causes of the mishap.[23]

3.1.3 Safety and Mission Assurance Functional Areas

While S&MA was broadly reported as a problem area by the instruments, no specific issue stands out. However, it should be noted that staffing was the number one reported issue within S&MA (47%) and several instruments specifically reported a lack of expertise as a problem. As a result, S&MA expertise was addressed as part of the overall staffing problem area.

3.1.4 Schedule Management (Common to Both Surveys)

Schedule management was reported as a top problem area by both the instruments (90%) and the general workforce (42%). The top two schedule management issues, as reported by the instruments, relate to schedule efficiency (67%) and ownership (61%) at the instrument subsystem level. In addition, 50% of the instruments reported that more scheduling support was needed than expected. The lack of scheduling support and schedule ownership at the subsystem level impedes the ability to effectively manage the instrument development.

The independent research supports the concept that owning and managing a schedule effectively will increase the likelihood of a successful instrument development. An investigation of cost and schedule growth history for forty science missions reported lessons learned from missions that experienced limited cost and schedule growth. One of these lessons learned is that managing to schedule and the effective use of Earned Value Management (EVM) should be applied to future missions to control cost and schedule growth.[5] This investigation also reported that instrument development problems were the largest contributors to project cost and schedule growth, which further supports focus on these schedule management issues from an instrument perspective.[5]

Another example from the independent research involved a highly successful instrument development, where delivery occurred one week earlier than the target date and met the target cost. Some of the key items cited as contributing to this success were excellent planning and schedule control, development of a very detailed schedule, and that the schedule was created and owned by the performing organizations.[8]

3.1.5 Organizational Interface

The top two organizational interface problems reported by the instruments were:

1. Lines of communication (57%); and
2. Lines of authority (54%).

A study from the independent research reported lessons learned from the government management of satellite developments. One lesson learned is that shared system performance responsibilities are complex relationships to implement due to different motivations:

1. The government wants to balance technical, cost, schedule performance, and risk; and
2. The contractor wants profit and shareholder value.

Another lesson learned is that clear lines of authority and responsibility must be defined, specifically, oversight, insight, and application of resources. The report also noted that open and honest communications with senior management are required.[6]

Two NASA Lessons Learned reports also highlight the importance of full and open lines of communication as essential to mission success.[4, 11]

3.1.6 Acquisition

Acquisition is the top reported problem area by the general workforce (93%). Within acquisition, unrealistic or optimistic cost (68%) and schedule (68%) baselines were the most reported specific issues.

These issues were addressed several times in the independent research. An investigation of cost and schedule growth history for forty science missions reported lessons learned from missions that experienced limited cost and schedule growth. One of the lessons learned was that robust and realistic initial estimates should be applied to future missions to control cost and schedule growth.[5] In addition, government lessons learned show that an initial cost estimate that is significantly inaccurate can doom a project to failure regardless of what other actions are taken.[5]

The research also showed that early cost estimates prepared when a mission's science concept is first proposed are frequently overly optimistic due to lack of a full understanding of the science scope and instrument complexity. Budget constraints based upon these early cost estimates normally preclude any funding increases.[4] The instrument project may then be forced to cope with unknown, understated, or perhaps unacceptable risk to comply with the funding cap. Under these conditions, the proposed mission assurance plan/funding is usually inadequate for the actual level of mission risk.[14]

According to another report, some items addressing these issues included: … most programs are budgeted at 50% probability; most programs have inadequate reserves; when reserves exist, they are often used for new requirements; unrealistic budgets lead to unrealistic program plans requiring inefficient/costly corrective action. All of these items contribute to schedule delays or excess program operational risk.[2]

3.1.7 Requirements Management

Requirements management was reported as a problem by 43% of the general workforce surveyed. Several issues in requirements management were also discovered in the independent research, such as insufficient traceability, requirements not defined early enough, and goals or desires stated as requirements.[4, 6, 7, 8, 15, 19, 20] These specific issues will be addressed further in section 3.3, Cross-Cutting Themes and Their Impact.

3.1.8 Contract Management

Contract management was reported as a problem area by 36% of the general workforce. In addition, contracts were reported by instruments as an organizational interface problem (46%). Contract and/or subcontract changes were often cited by the instruments as a contract management issue. Types of changes referenced included: contractor or subcontractor management, the contract itself, and direction. In addition, there were various contract management issues cited by the instruments specifically related to subcontract management. Examples of these were: diverging priorities between the prime contractor and the government; conflicts between the contractor and subcontractor; and subcontractor-supplier management. The independent research also points to the need for prime contractors to manage subcontractors instead of intervening only when problems occur.[6]

3.2 Inter-Process Discussion

In an effort to look for additional patterns in the data, the Study team defined three different populations of instruments. These populations included: more versus less complex, higher versus lower risk, and challenged versus successful instrument developments. The patterns discovered in these populations, as described in this section, highlight areas that instrument managers may want to pay attention to during development. The definitions for each of these populations are given in the sections below.

3.2.1 More versus Less Complex Instrument Developments

Instrument developments are often found to be complex not only due to their cutting edge technology or difficult technical requirements, but also because of their risk posture and complex interfaces. Additionally, the lack of flight heritage can make instrument developments more challenging. Given these factors, the objective of this assessment was to determine whether complex instrument developments were more or less likely to have cost overruns, schedule delays, or technical problems.

The first step the Study team took was to consider what constituted a *more complex* instrument development. After much consideration and discussion, more complex instruments developments were defined as those that reported:

- Complex interfaces; or
- Requirements too complex; or
- Low (Technology Readiness Level (TRL) or flight heritage and a large budget or schedule; or
- Low TRL or flight heritage and configuration management processes that required a higher level of support than anticipated or available; or
- High risk posture and a large budget or schedule; or
- More than four primary partners involved in the design and fabrication of the instrument.

Based on this definition, a total of 25 of the 41 instruments were determined to be more complex developments. Once the instruments were binned into the two groups, each group was assessed based on the problems they encountered as well as their cost, schedule, and technical performance. Those results are discussed in the following two sections.

3.2.1.1 Problem Areas Reported More Often by Complex Instrument Developments

Figure 3.2.1.1-1 shows the percentage of more complex and less complex instrument developments that reported problems in the areas shown. It also shows the differential between the two groups. The problem area with the largest differential, or the one reported more often by complex instruments, was configuration management. More complex instruments were 1.7 times more likely to report problems in this area. One of the configuration management issues complex instruments reported more often was that multiple versions of documentation were being implemented at the same time.

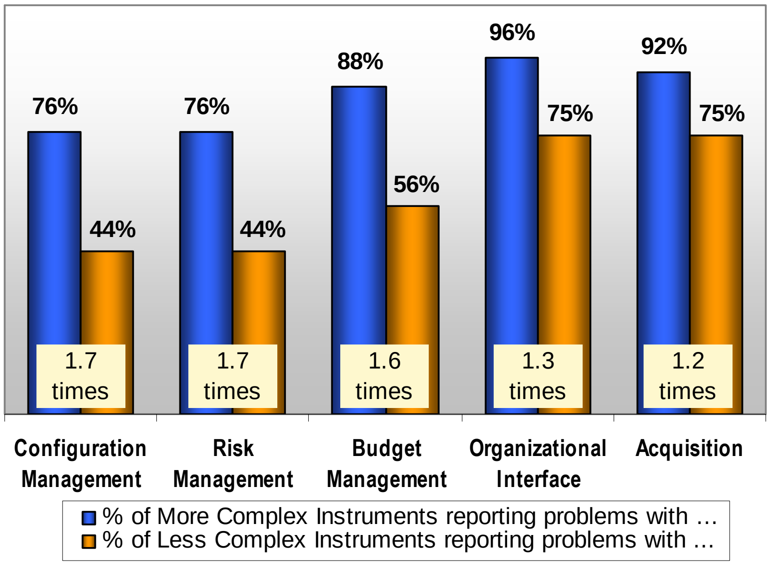

Figure 3.2.1.1-1. Problem Areas with Highest Differentials between More and Less Complex Instruments

The next two problem areas, which were reported approximately twice as often by the more complex instruments, were risk management and budget management. In the area of risk management, complex instruments reported that:

1. Risks were not identified regularly;
2. Timely communication of risks was difficult; and
3. They lacked resources to analyze all identified risks.

As for budget management issues, approximately half of the more complex instruments and none of the less complex instruments reported problems with changes in budget phasing or allocations. The more complex instruments were also more likely to report that:

1. Incremental funding caused schedule delays;
2. Budget changes were not clearly communicated; and
3. The budget was not integrated early enough.

The remaining two problem areas, organizational interface and acquisition, were reported 1.3 and 1.2 times more often by the more complex instruments. The top issue reported by the more complex instruments in each of these areas was problems with lines of communication and insufficient allocated schedule, respectively. Another organizational interface problem reported by the more complex instruments was issues with lines of authority. As for acquisition, issues that were cited more often included:

1. Unrealistic or optimistic schedule baseline;
2. Insufficient allocated budget or cost cap;
3. Supplier experienced cost growth or schedule delays; and
4. Procurement issues caused cost growth and schedule delays.

Once the problem areas and specific issues were identified, the Study team evaluated whether there were any correlations between instrument development complexity and cost, schedule, and technical performance. Those results are discussed below.

3.2.1.2 *Performance of More and Less Complex Instruments versus the Success Indicators*

Figure 3.2.1.2-1 shows the performance of the more and less complex instruments versus the primary success indicators. It is interesting to note that while there was only a minor correlation between complexity and cost overruns, there was a major correlation between complexity and schedule delays. More complex instrument developments were 3.2 times more likely to have schedule delays of 5 months or more. Technical performance is represented by those populations citing design deficiencies or workmanship/technical problems contributing to cost growth and/or schedule delays. Complex instruments were approximately twice as likely to experience problems in these areas as well.

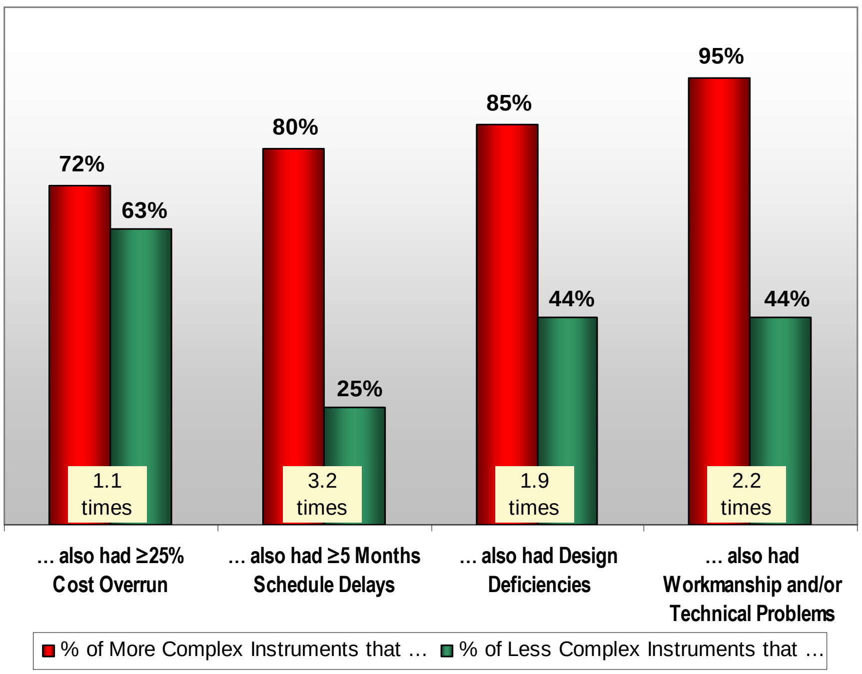

Figure 3.2.1.2-1. More and Less Complex Instruments versus the Primary Success Indicators

3.2.1.3 *Summary*

The data showed correlations between the complexity of instrument development and an increased likelihood of encountering problems with configuration management, risk management, budget management, organizational interfaces, and acquisition. The data also showed that more complex instruments were more likely to have schedule delays of 5 months or more and experience design deficiencies or workmanship/technical problems. This information increases awareness of these types of issues for complex instruments and allows projects to outline potential mitigations in case the issues are realized.

3.2.2 *Higher versus Lower Risk Instrument Developments*

Instruments typically are viewed as higher risk mission elements compared to spacecraft, launch vehicles, or ground systems because many are unique, first time developments, and they often possess technologies with low TRLs. The Study team viewed instrument risk as an important characteristic and thus decided to define risk populations from the IS data to enable an understanding of the differences between higher and lower risk instrument developments. In addition, the Study team plotted the higher versus lower risk populations against the technical, cost, and schedule parameters to further evaluate these populations.

The Study team developed criteria for *higher risk* instruments based on thorough discussions of the Study surveys, and general knowledge of instrument development and risk. The criteria for higher risk instruments were defined as those that reported:

- Low TRL/flight heritage and cost/schedule "pressure" (aggressive or unrealistic), or
- Requirements too complex, or
- Medium risk posture and cost/schedule "pressure"(aggressive or unrealistic), or
- A "high" risk posture.

A total of 25 out of 41 instruments were defined as higher risk based on the criteria above. Once the instruments were split into higher risk and lower risk populations, each group was assessed based on the problems they encountered as well as their cost, schedule, and technical performance.

3.2.2.1 Problem Areas Reported More Often by Higher Risk Instrument Developments

A comparison of the higher versus lower risk instruments was analyzed across the instrument development processes. The top five problem areas with the highest differentials between the higher and lower risk instruments are shown in figure 3.2.2.1-1. The problem area with the highest differential was contract management. Higher risk instruments were 3.5 times more likely to report problems in contract management than lower risk instruments. This problem was discussed in section 3.1.8 as part of the top five problem areas reported by the general workforce survey respondents. Instrument survey respondents also reported issues with contract management.

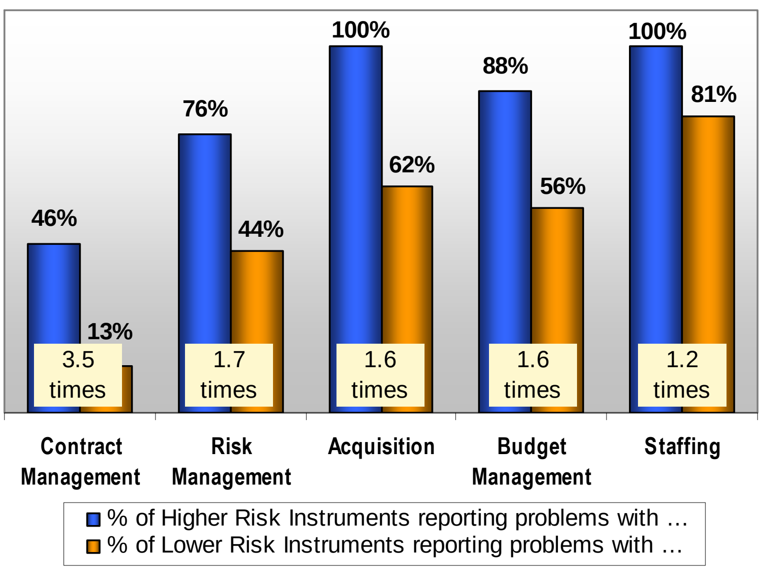

Figure 3.2.2.1-1. Problem Areas with Highest Differentials between Higher and Lower Risk Instruments

The second problem area was risk management. This problem was reported 1.7 times more often by the higher risk instruments. Specific issues reported for risk management included:

1. Tracking tool difficult to use (none of the lower risk instruments reported this issue);
2. Lacked resources to implement mitigation plans;
3. Risks were not regularly identified; and
4. Timely communication of risks was difficult.

It is worth noting that higher risk instruments were 4.6 times more likely to report a lack of resources to implement risk mitigation plans.

The next two problem areas, acquisition and budget management, were reported 1.6 times more often by the higher risk instruments. Higher risk instruments reported the following specific acquisition issues:

1. Insufficient allocated budget or cost cap;
2. Unrealistic or optimistic schedule baseline;
3. Insufficient allocated schedule;
4. Unrealistic or optimistic cost baseline; and
5. Problems with the acquisition process.

It is worth noting that insufficient allocated budget or cost cap was reported 8 times more often by the higher risk instruments.

In addition, the following issues were reported approximately 3 times more often by higher risk instruments: unrealistic or optimistic schedule baseline, insufficient allocated schedule, and unrealistic or optimistic cost baseline.

In the area of budget management, higher risk instruments reported the following specific issues:

1. Budget not integrated early enough (none of the lower risk instruments reported this issue);
2. Changes in budget allocation or phasing;
3. Incremental funding caused schedule delays;
4. Budget changes not clearly communicated; and
5. Insufficient time to update budget at the lowest level.

In addition, the following issues were reported over 5 times more often by the higher risk instruments: changes in budget allocation or phasing, incremental funding that caused schedule delays, budget changes not clearly communicated, and insufficient time to update the budget at the lowest level.

The last problem area reported, staffing, was reported 1.2 times more often by the higher risk instruments. Specific staffing issues reported by the higher risk instruments included:

1. Performance related staffing changes;
2. Critical knowledge limited to a few individuals;
3. Understaffing;
4. Difficulty finding expertise; and
5. Attrition.

It is worth noting that higher risk instruments were 3.5 times more likely to report performance-related staffing changes, 1.7 times more likely to be understaffed, and 1.4 times more likely to have critical knowledge limited to a few individuals.

3.2.2.2 Performance of Higher or Lower Risk Instruments versus the Success Indicators

Figure 3.2.2.2-1 shows the performance of the higher and lower risk instruments versus the primary success indicators: cost, schedule, and technical performance. Higher risk instrument developments were more than twice as likely to experience cost overruns and more than 3 times as likely to experience schedule delays. In addition, higher risk instrument developments were more likely to experience design deficiencies and workmanship/technical problems contributing to cost growth/schedule delays compared to lower risk instruments.

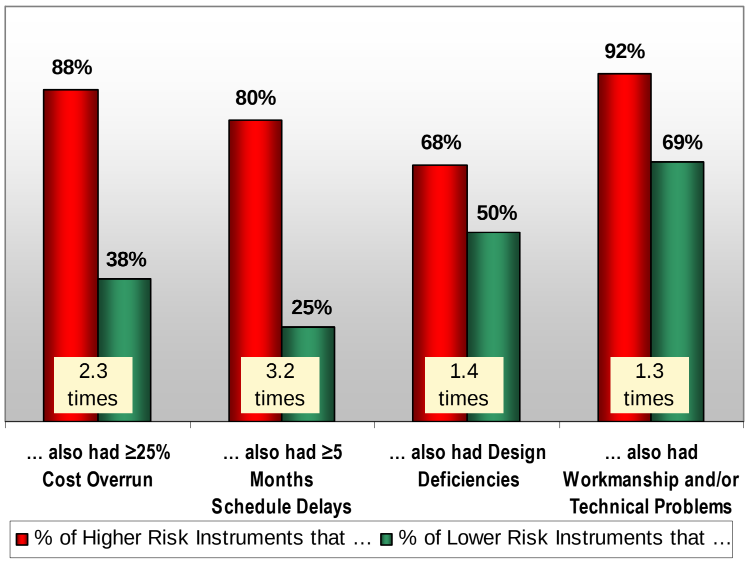

Figure 3.2.2.2-1. Higher and Lower Risk Instruments versus the Primary Success Indicators

3.2.2.3 Summary

The data showed that higher risk instrument developments had an increased likelihood of encountering problems with contract management, risk management, acquisition, budget management, and staffing. The Study data also shows that higher risk instrument developments were 2 to 3 times more likely to have cost overruns and schedule delays compared to the lower risk instruments. In addition, higher risk instrument developments were more likely to experience design deficiencies and workmanship/technical problems. This data provides a snap shot of the types of problems that higher risk instrument developments encountered. Future instrument teams may decide to use this information as part of a risk mitigation strategy.

3.2.3 Challenged versus Successful Instruments

This section shows the top five cross-cutting problem areas by correlation with cost and schedule as reported by the instruments. This is followed by the top specific issues within these problem areas. These relationships were identified by using two instrument populations, *challenged and successful*, as defined below:

- Challenged instruments: ≥25% cost overrun and ≥5 months schedule delays
- Successful instruments: <25% cost overrun and ≤4 months schedule delays

A total of 20 out of 41 instruments were defined as challenged and a total of 9 out of 41 instruments were defined as successful. Twelve instruments were excluded because they did not meet both criteria in the challenged or successful populations.

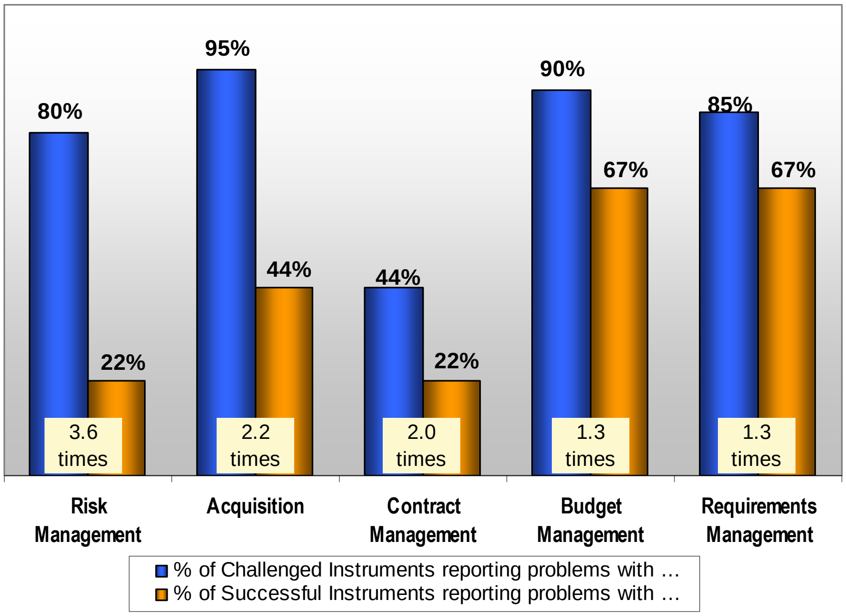

Figure 3.2.3-1. Problem Areas with Highest Differential between Challenged and Successful Instruments

As shown in figure 3.2.3-1, the risk management problem area was cited 3.6 times more often by the challenged instruments than the successful instruments.

The top specific issues within the problem areas in figure 3.2.3-1 follow.

3.2.3.1 Risk Management

As shown in figure 3.2.3.1-1, challenged instruments cited risk management resource problems 5 times more often than successful instruments, which likely contributed to two additional problems, risks not regularly identified and issues with timely communication of risks.

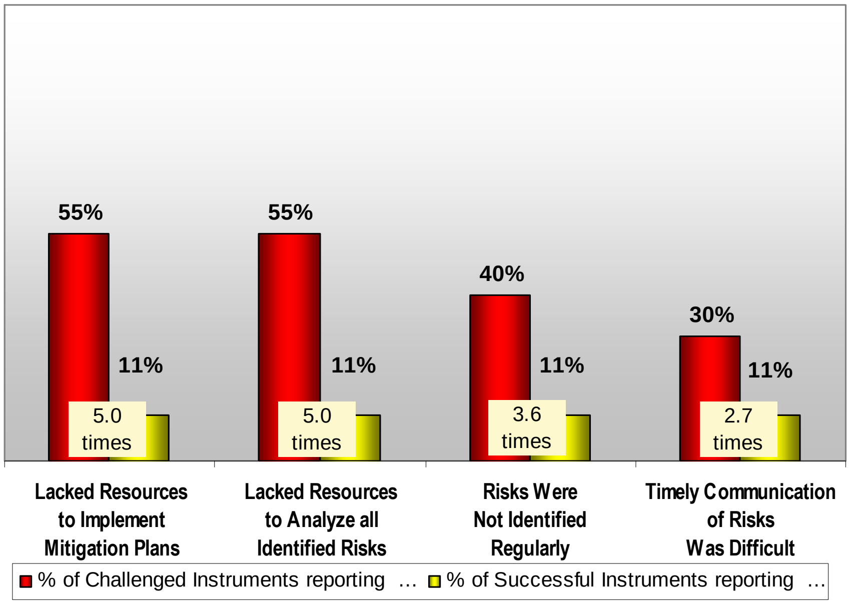

Figure 3.2.3.1-1. Specific Risk Management Issues

The independent research supports the importance of effective risk management as evidenced by a MIB assessment of eight missions. The MIB found that the root causes and contributing causes of mission mishaps were organized into recurring areas or themes, and incomplete risk management/analysis was one of these themes. Risk management is a continual process and must be performed throughout the life of the project. All risks should be identified as early as possible in order to assess which risks are capable of being controlled and what the acceptable risk level is for each project. When changes occur, risks must be re-assessed. When risks are identified they must be communicated to everyone who may be affected by them.[24] Several other examples found in the independent research emphasize the need to actively address risk throughout the lifecycle of the program, which includes addressing risk early, and establishing an effective risk management plan in the beginning.[4, 8, 16, 18] This all highlights the need for adequate resources to be in place in order to effectively perform risk management.

3.2.3.2 Acquisition

Challenged instruments cited unrealistic cost or schedule baselines 7 to 8 times more often than successful instruments (see figure 3.2.3.2-1). In addition, three of the four acquisition issues reported by the general workforce were also reported by the instruments: unrealistic or optimistic cost, unrealistic or optimistic schedule baseline, and insufficient allocated budget or cost cap (as reported in section 3.1.6). These problems are also corroborated by the independent research as discussed in section 3.1.6.

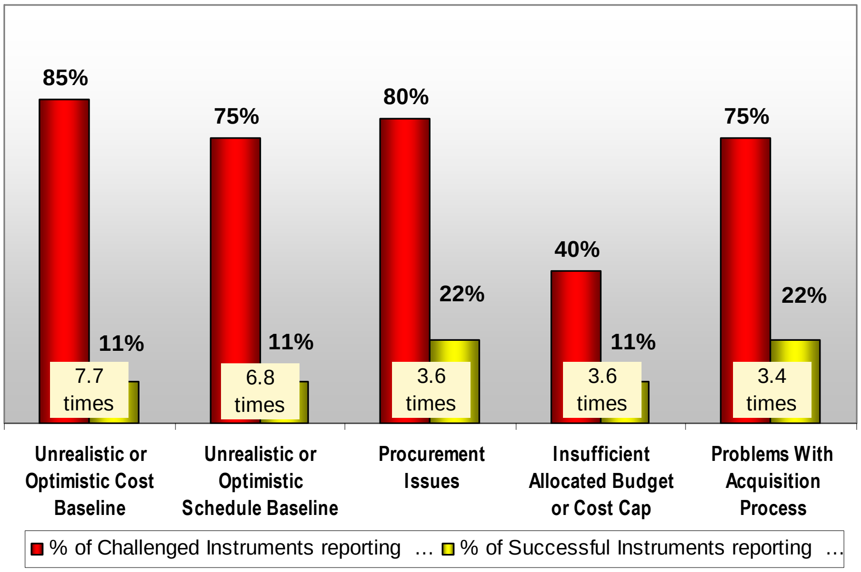

Figure 3.2.3.2-1. Specific Acquisition Issues

Figure 3.2.3.2-1 also shows that challenged instruments cited procurement issues 3.6 times more often than successful instruments. Specifically, the lack of timeliness in procurement was cited several times by the instruments.

3.2.3.3 Contract Management

Approximately one third of the instruments and general workforce indicated that they encountered contract management issues during instrument development. Overall, instruments that reported contract management issues were 1.5 times more likely to have 25% or more cost overruns. Although contract management problems were not reported by the instruments as often as other problems, challenged instruments were 2 times more likely to have problems in this area than successful instruments.

3.2.3.4 Budget Management

Three of the top five issues cited by the challenged instruments are driven by external factors (changes in budget allocation or phasing, incremental funding caused schedule delays, and budget changes not clearly communicated) as shown in figure 3.2.3.4-1. Stakeholders should keep these factors in perspective when making budget decisions as to how they may impact cost and schedule performance at the instrument level.

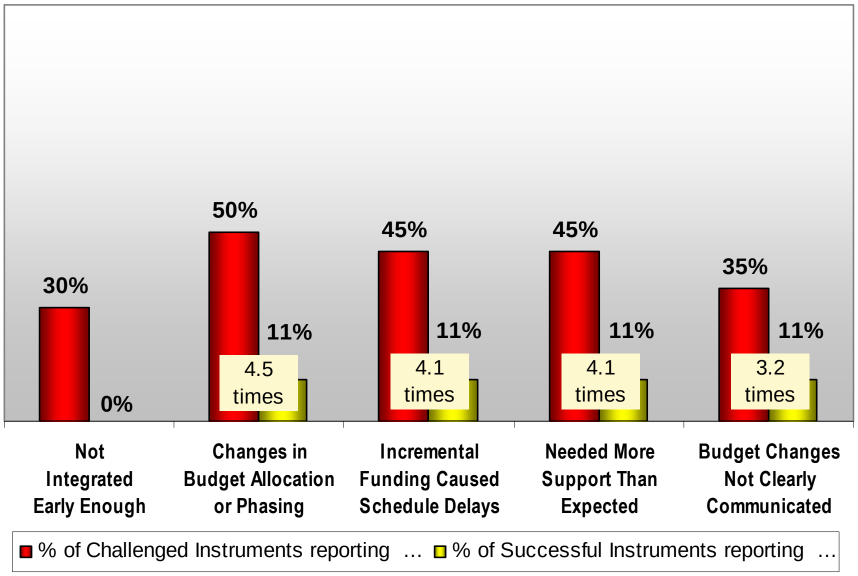

Figure 3.2.3.4-1. Specific Budget Management Issues

3.2.3.5 Requirements Management

As shown by figure 3.2.3.5-1, requirements management problems were encountered much more frequently by challenged instruments than by successful instruments. The top two requirements issues indicate that poor requirements formulation is correlated with the challenged instruments (no correlation with successful instruments). The last three issues in the figure pertain to requirements changes which are correlated almost exclusively with challenged instruments.

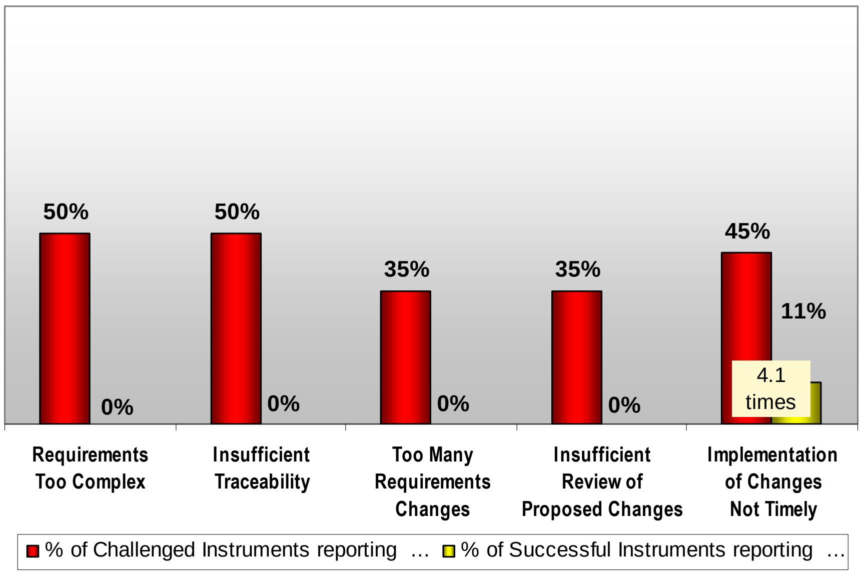

Figure 3.2.3.5-1. Specific Requirements Management Issues

Requirements management was the third most reported problem by the general workforce. As mentioned in section 3.1.7, several issues in requirements management were also highlighted in the independent research related to insufficient traceability, requirements not defined early enough, and goals or desires stated as requirements.

3.2.3.6 Summary

The data showed that challenged instrument developments had an increased likelihood of encountering problems with risk management, acquisition, contract management, budget management, and requirements management. It is also worth mentioning that the Study also cited the following problems/issues more often by the challenged instruments than the successful instruments:

1. Risk management problems (3 to 4 times);
2. Risk management resource issues (5 times); and
3. Unrealistic cost or schedule baseline (7 to 8 times).

Finally, the data also showed that challenged instruments were driven by budget management external factors and poor requirements formulation issues were correlated with the challenged instruments, while no correlation existed with the successful instruments. The same trend was seen with requirements changes, which were correlated almost exclusively with challenged instruments.

3.3 Cross-Cutting Themes and Their Impact

In an effort to determine the factors that impact instrument development processes, the Study team examined data from both the Instrument and General Workforce Surveys. This allowed the Study team to understand specific issues within each of the instrument development process areas and how they correlated with instrument cost, schedule, and technical performance. The team then scanned across all processes and issues to develop common, overarching themes. This effort culminated in the identification of five Study themes: staffing, acquisition, systems engineering, instrument management, and testing issues. The following sections discuss each theme, the specific problems within each theme, and their impact on instrument development.

3.3.1 Staffing

To remain a leader in aeronautics, space, and technology innovations, NASA will need to continue to attract, train, and retain talented staff. However, the pipeline of science and engineering talent is shrinking at the same time that the demand is increasing in the private sector.[10, 21] Additionally, according to the Office of Personnel Management, 60.8% of the full-time permanent federal workforce (as of October 2006) will be eligible to retire by the year 2016.[24] Due to these factors, it came as no surprise that staffing was one of the top areas identified as an issue by the instruments, general workforce, and the independent research.

93% of the instruments and 92% of the general workforce reported problems with staffing; however, the data showed that there are four pervasive staffing challenges facing instrument development: lack of project resources, lack of expertise, understaffing, and team turnover.

3.3.1.1 Project Resource Issues and Impact

Instrument managers often face unique challenges associated with having to build a technologically advanced science instrument that meets the requirements and remains within the technical, budget, and schedule constraints. Instrument managers, like project managers, have to manage their instrument's budget, schedule, and risks, as well as oversee configuration management activities. And, while instrument managers typically have lead systems engineers supporting them, to do their job successfully, they require additional resources/people (i.e., project staff) with the appropriate level of expertise in these areas. Yet, as shown in figure 3.3.1.1-1, as many as two-thirds of the instruments reported that they lacked appropriate resources in the aforementioned areas. Percentages are based on the population of instruments that reported problems in a particular area, e.g., risk management, configuration management, etc. More specifically, 65% indicated that they lacked the resources to implement risk mitigation plans and half reported that they lacked the resources to analyze all identified risks. The instruments that reported these risk management problems were 1.6 times more likely to have 25% or more cost overrun and 1.4 to 1.8 times more likely to have schedule delays of 5 months or more. Furthermore, instruments that had poor cost and schedule performance cited risk management resource issues 5 times more often than instruments that had good cost and schedule performance.

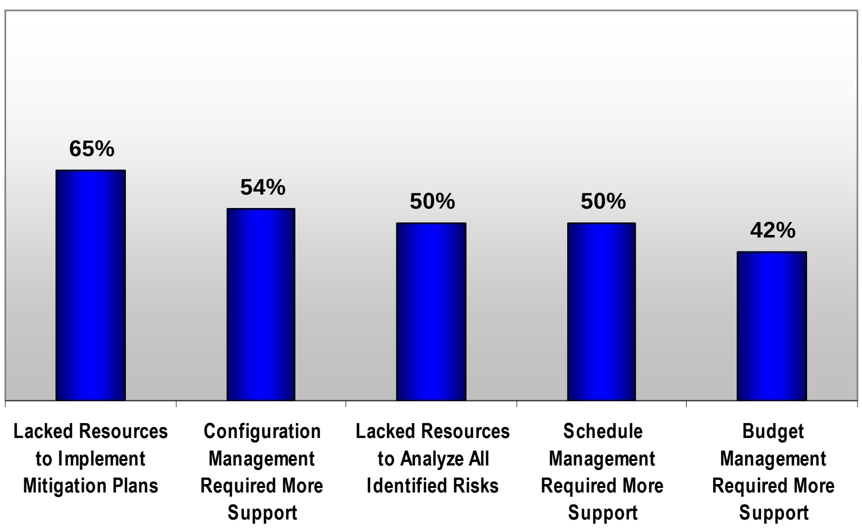

Figure 3.3.1.1-1. Project Resource Issues Reported by Instruments

The instruments also reported needing a higher level of support than anticipated or available for configuration, schedule, and budget management. Instruments that reported budget management resource issues were 1.6 times more likely to experience a cost growth of 25% or more. When the Study team examined challenged versus successful instruments, budget resource issues were cited 4.1 times more often by the challenged instruments. Finally, instruments that reported resource issues with configuration or schedule management were more likely to experience schedule delays (1.2 times and 1.4 times, respectively).

3.3.1.2 *Expertise Issues and Impact*

Figure 3.3.1.2-1 shows the top staffing issues instruments cited as related to expertise. Percentages are based on the population of instruments that reported problems with staffing. The number one problem reported was that critical knowledge was limited to a few individuals (68%). Instruments that reported this problem were 1.5 times more likely to have a cost overrun of 25% or more and 2.2 times more likely to have schedule delays of 5 months or more.

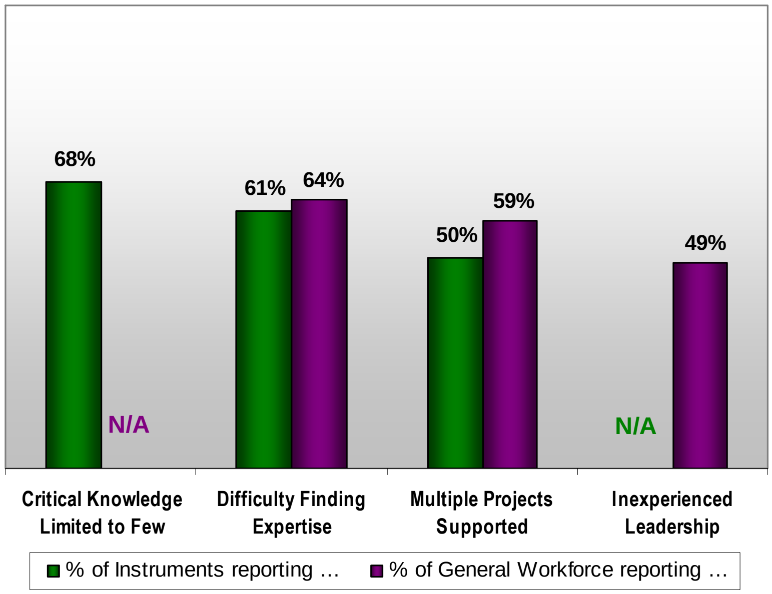

Figure 3.3.1.2-1. Staffing Expertise Issues Reported by Instruments and General Workforce

The second issue, which was reported by both the instruments (61%) and general workforce (64%), was difficulty finding personnel with the requisite technical expertise and/or experience. Instruments that reported this problem also experienced both cost overruns (1.7 times) and schedule delays (1.6 times) at a higher rate than those who did not cite this as a problem.

The general workforce found team members supporting multiple projects more problematic than the instruments (59% and 50%, respectively). The last problem in this area, which was reported solely by the general workforce, was inexperienced leadership (49%).

3.3.1.3 Staffing Level Issues and Impact

The third major staffing problem cited by instruments and general workforce was understaffing. Percentages shown in the graph are based on the population of instruments that reported problems in a particular area, e.g., safety and mission assurance, staffing, etc. As shown in figure 3.3.1.3-1, safety and mission assurance staffing issues such as understaffing, lack of experience, and lack of availability were reported by 47% of the instruments. These instruments were 1.2 times more likely to have a cost overrun of 25% or more and 1.4 times more likely to have schedule delays of 5 months or more. Both the instruments (45%) and general workforce (38%) reported that project teams were understaffed. Instruments who reported this problem were 1.4 times more likely to have a cost overrun of 25% or more and 1.2 times more likely to have schedule delays of 5 months or more.

In the area of verification and validation:

1. 35% of the general workforce reported that people and/or facilities were unavailable during verification and validation;
2. 38% of the instruments reported that staffing issues caused schedule delays during testing; and
3. 32% of the instruments reported that staffing issues caused cost growth during testing.

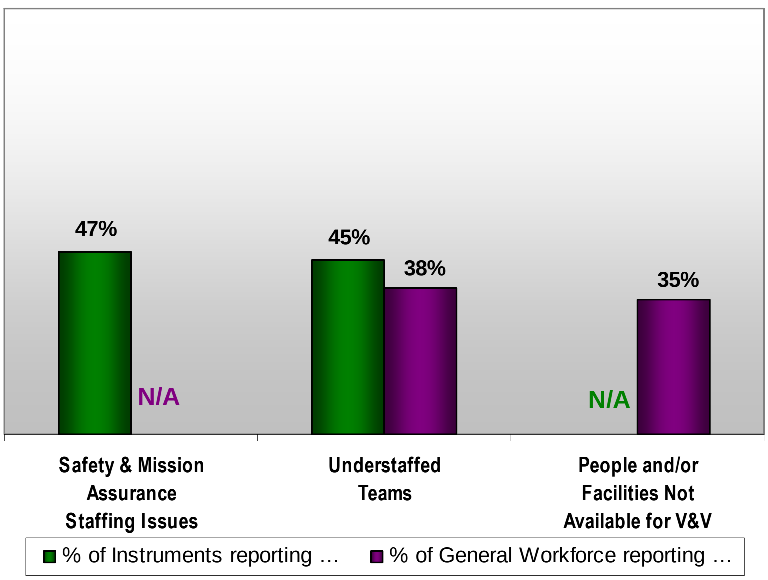

Figure 3.3.1.3-1. Staffing Level Issues Reported by Instruments and General Workforce

3.3.1.4 Team Turnover Issues and Impact

As shown in figure 3.3.1.4-1, the last major staffing issue cited by the respondents was related to team turnover. Percentages shown in the graph are based on the population of instruments that reported problems in a particular area, e.g., changes in leadership, turnover, or staffing. The impacts associated with team turnover were non-trivial. Instruments that reported a medium or high rate of team turnover were 1.5 times more likely to experience a cost overrun of 25% or more and 1.9 times as likely to experience schedule delays of 5 months or more. Over half of the instruments reported more than two changes in key leadership positions during instrument developments. They were 1.6 times more likely to perform poorly on cost and more than twice as likely to perform poorly on schedule. The instruments that indicated they had performance-related staffing changes were 1.5 times more likely to have cost overruns and schedule delays. Lastly, the instruments that cited attrition as a problem were 1.5 times more likely to have schedule delays.

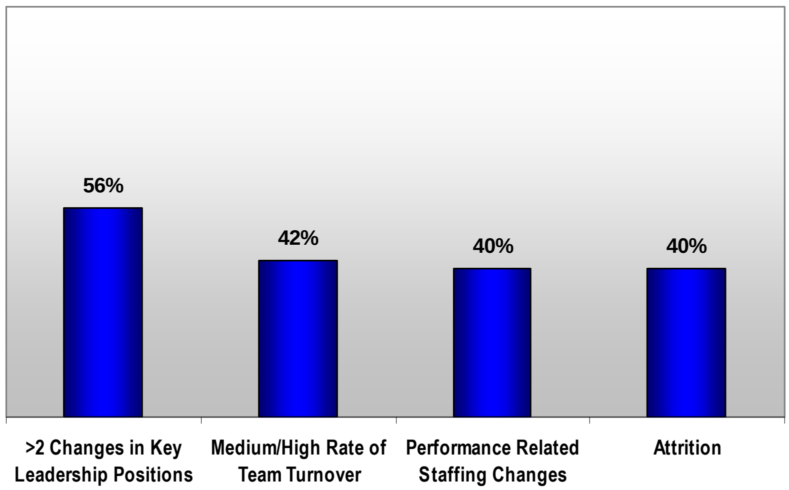

Figure 3.3.1.4-1. Team Turnover Issues Reported by Instruments

3.3.1.5 Relevant Independent Research

People are a project's most important resource. They affect the project's performance and represent its knowledge base. When an organization's staffing or expertise levels are inadequate, its ability to effectively manage its programs is jeopardized. This is evidenced by the data collected by the Study team. These findings are well supported by the independent research also, which addresses staffing issues during project formulation and implementation phases.

For example, the Science Support Office (SSO) at NASA's Langley Research Center directed a study of the Technical Management and Cost (TMC) evaluation of proposals submitted for Principal Investigator-led (PI-led) science missions. The report showed that management plans were a source of major weaknesses in 27% of these proposals. In addition, some common staffing trends identified were: "lack of demonstrated organization or individual expertise for the specific role identified" and "low time commitments for essential members of the core management team".[1] This relates to expertise issues as discussed in section 3.3.1.2.

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[1] Perry, B. R., et al. *Lessons Learned from Technical, Management, and Cost Review of Proposals, A Summary of 10 Years Experience in Reviewing Competitively Selected Proposals for New Science Missions*, pp 7.

The TMC also identified "lessons learned" to improve the overall quality and maturity of the proposals, thereby increasing the chances of selection. It is interesting to note that four of the six areas identified by the SSO study were common to the NICS Study themes. In addition to the staffing issue discussed above, the other three common areas identified by the SSO included: cost and reserve, instrument implementation, and systems engineering.[9]

Another example of the impact of staffing, during the implementation phase, involves a MIB, which conducted a lengthy investigation to better understand the issues that led to the failure of a particular spacecraft. The major issues highlighted by the MIB include: significant project cuts in monetary and personnel resources available to support the mission, failure to adequately instill a mission success culture that would minimize the risk introduced by these cuts, and project leadership deficiencies introduced sufficient risk to compromise mission success, to the point of mission failure.[4] In addition, many of the projects examined in another study reported problems with employee fatigue, stress-related ailments, and retaining key staff.[3] This relates to staffing levels and team turnover issues as discussed in sections 3.3.1.3 and 3.3.1.4, respectively.

In summary, staffing is often one of the most challenging tasks that instrument managers face. The success of instrument development directly depends on the skills and capabilities of the people on the instrument team. As such, it is critical that instrument teams are staffed with personnel with the appropriate skills, abilities, and experience to successfully execute the instrument development.

3.3.2 Acquisition

In a report entitled *Space Acquisitions: Major Space Programs Still at Risk for Cost and Schedule Increases,* the Government Accountability Office (GAO) found that:

> "the majority of acquisition programs in DoD's space portfolio have experienced problems during the past two decades that have driven up cost and schedules and increased technical risks….past work has indentified a number of causes behind the cost growth and related problems. These include: optimistic cost and schedule estimating; the tendency to start programs with too many unknowns about technology; inadequate contracting strategies; contract and program management weaknesses; the loss of technical expertise; capability gaps in the industrial base; tensions between labs that develop technologies for the future and acquisition programs; divergent needs in users of space systems, and diffuse leadership."[2]

In line with the findings from the GAO report, both the instruments (85%) and general workforce (93%) overwhelmingly reported that there were problems associated with the acquisition process. The primary issues were focused in the areas of procurement, cost and schedule estimating and allocations, problems with suppliers, and contract management.

3.3.2.1 Procurement Issues and Impact

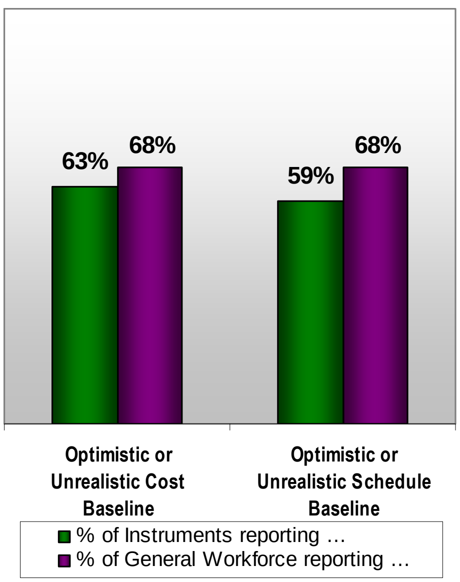
This section outlines the various procurement issues reported by the instruments. Several of the instruments indicated that they had problems getting procurements completed in a timely manner and that they experienced delays in awarding contracts. The problems were exacerbated by issues between prime and subcontractors and specialized work being limited to a few vendors. 41% of the instruments reported that the imposition of new programmatic scope, such as new policy issuance, introduction of earned value

[2] Chaplain, C.T., *Space Acquisitions: Major Space Programs Still at Risk for Cost and Schedule Increases* (GAO-08-552T), (United States Government Accountability Office Acquisition, March 4, 2008) pp i.

management, changes in procurement strategy, etc. caused cost growth. These instruments were 1.3 times more likely to have a 25% or more cost overrun. Approximately half (49%) of the instruments reported that they had parts, subsystems, or instrument-level procurement issues that caused schedule delays. Challenged instruments were 3.6 times more likely to report this as a problem than successful instruments. Moreover, instruments that had this problem were 2.3 times more likely to have schedule delays of 5 months or more.

3.3.2.2 Optimistic Cost/Schedule Baselines and Impact

Figure 3.3.2.2-1 shows the percentage of all instruments, the general workforce, and the challenged and successful instruments which reported that their instrument development cost or schedule baselines were unrealistic or optimistic. These baselines were established by the instruments at proposal selection or contract award. Approximately 60% of the instruments and more than two thirds of the general workforce reported that their instrument's cost or schedule baselines were unrealistic. When evaluating the challenged instruments versus the successful instruments, one can see that the challenged instruments were 7 to 8 times more likely to indicate that their schedule and cost baselines were unrealistic or optimistic. However, it is interesting to note that one fourth of the challenged instruments reported that their schedule baseline was realistic.



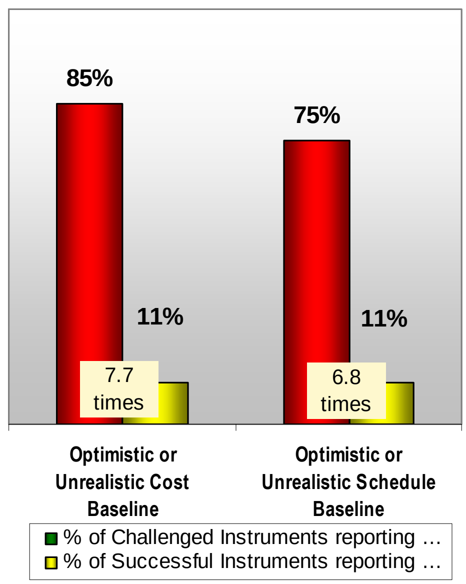


Figure 3.3.2.2-1. Optimistic/Unrealistic Cost or Schedule Baseline

Instruments that reported that their cost baseline was unrealistic/optimistic were 2.7 times more likely to have 25% or more cost overruns, 2.1 times more likely to have design deficiencies contributing to cost overruns, and 1.7 times more likely to have workmanship or technical problems contributing to cost overruns. Similarly, instruments that reported that their schedule baseline was unrealistic/optimistic were 2.7 times more likely to have schedule delays of 5 months or more, 1.6 times more likely to have design deficiencies contributing to schedule delays, and 1.5 times more likely to have workmanship or technical problems contributing to schedule delays.

3.3.2.3 Insufficient Allocated Budget/Schedule and Impact

Figure 3.3.2.3-1 shows the percentage of all instruments, the general workforce, and the challenged and successful instruments that indicated they had an insufficient allocated budget or schedule. These allocations were set by NASA in the Announcement of Opportunity. Approximately 60% of the general workforce reported insufficient allocated budget or schedule, whereas the instruments reported these issues at a lower rate.

Insufficient allocated budget was 3.6 times more likely to be reported by the challenged instruments than the successful instruments. Challenged instruments also reported insufficient allocated schedule 2.7 times more often than successful instruments.

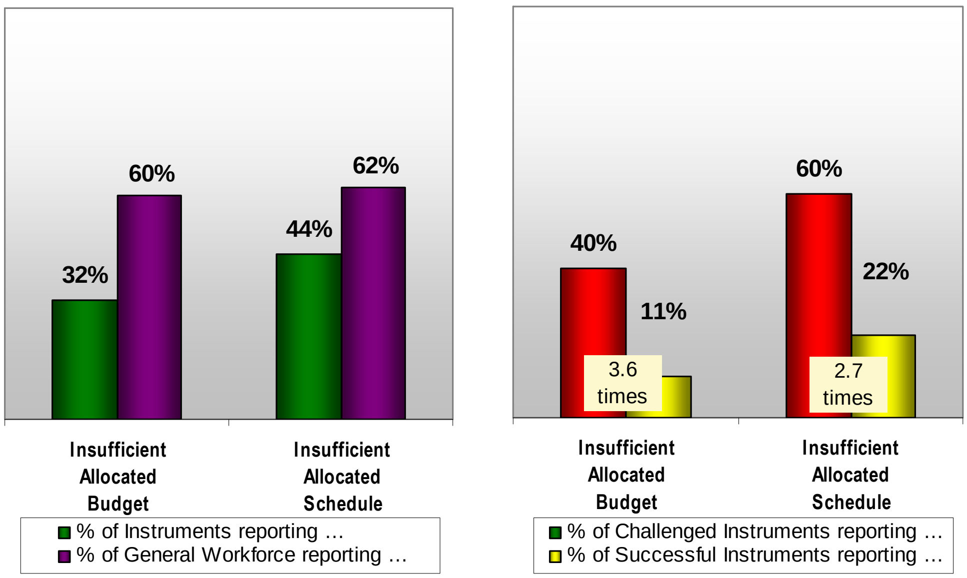


Figure 3.3.2.3-1. Insufficient Allocated Budget or Schedule

Instruments that reported that their allocated budget was insufficient were 1.4 times more likely to have 25% or more cost overruns. Similarly, instruments that reported that their allocated schedule was insufficient were 1.5 times more likely to have schedule delays of 5 months or more.

3.3.2.4 Supplier Issues

The issue of suppliers having experienced cost growth or schedule delays was reported by 66% of the instruments. Multiple instruments reported that hardware was delivered late because they used a new contractor or components were delivered late from vendors. Quality control issues with vendors also resulted in schedule delays. Lastly, the instruments reported that parts issues and failures resulted in significant schedule delays.

3.3.2.5 Contract Management

Approximately one third of the instruments and general workforce indicated they encountered contract management issues during instrument development. One specific contract management issue reported by instruments was that contractor rates change. These instruments were 1.7 times more likely to have schedule delays of 5 months or more. Instruments also reported problems with the contracted workforce resulting from company buy-outs or litigations. These instruments were twice as likely to have schedule delays of 5 months or more. Overall, instruments that reported contract management issues were 1.5 times more likely to have 25% or more cost overruns. The challenged instruments were twice as likely to have this problem as successful instruments and the higher risk developments were 3.5 times more likely to have this problem than the lower risk developments.

3.3.2.6 Relevant Independent Research

The acquisition process is an integral part of the instrument development lifecycle. Of the four issues discussed in the acquisition section, the driving issue is clearly optimistic cost and schedule baselines. In addition to the Study data showing this as a critical issue, the independent research shows that government and industry both feel pressures to underestimate cost and schedule.

For example, a review of the acquisition programs of the DoD showed that they have a history of cost growth, especially true for space systems. In response to historically high cost growth in the acquisition of space systems, the Air Force acquisition community supported the development of independent, accurate, and timely cost analyses to make the acquisition of space systems more realistic in terms of estimated costs.[27] This relates to the optimistic/unrealistic cost and schedule baseline issues as discussed in section 3.3.2.2.

In another source, a task force on acquisition of National Security Space Programs highlighted four key points on this topic:

1. Cost has replaced mission success as the primary driver in managing acquisition processes, resulting in excessive technical and schedule risk;
2. The space acquisition system is strongly biased to produce unrealistically low cost estimates throughout the acquisition process. These estimates lead to unrealistic budgets and un-executable programs;
3. Government capabilities to lead and manage the acquisition process have seriously eroded; and
4. While the space industrial base is adequate to support current programs, long-term concerns exist.[1] This also relates to the optimistic/unrealistic cost and schedule baselines issue, as discussed in the section referenced above.

In addition, a paper investigated recent NASA cost and schedule growth history of a series of Space and Earth science missions and associated programs. The data highlighted that the majority of projects had experienced substantial cost and schedule growth. Moreover, the data highlighted that the primary internal reason for cost and schedule growth was instrument development issues. Specifically, this paper suggested that the key potential causes for the growth experienced were: inherent optimism in initial design and estimates and instrument technical problems. It was also noted that the cost and schedule growth due to instrument problems more than doubled the growth caused by spacecraft problems. The paper also stated that elimination of instrument problems would significantly reduce the cost growth experienced by projects. If an instrument was in the critical path for development, any schedule delay would result in a "marching army" cost. Best practices were also identified in the following areas: proper mission scoping, robust initial cost and schedule estimates, and the importance of managing to the schedule, among others.[5] This further supports the unrealistic baseline issues and relates to the insufficient allocated budget/schedule as discussed in section 3.3.2.3.

In summary, there is widespread recognition concerning the lack of realism in government and industry program cost/schedule baselines. To mitigate these problems, a concerted effort needs to be made to improve these baselines from initial concept development up to contract source selection and to periodically review them during program execution.

3.3.3 Systems Engineering

Systems engineering is a critical discipline in developing science instruments. It allows for a methodical, disciplined approach for design, realization, technical management, operations, and retirement of an instrument.[26] Systems engineering includes a well known set of technical processes, of which some of the key functions are:

1. Defining and managing requirements;
2. Balancing technical risks;
3. Helping to manage changes and their impacts;
4. Monitoring technical progress through reviews; and
5. Verifying requirements.

The following sections examine challenges the instruments and general workforce reported in these areas, as well as the impact these challenges had on instrument development.

3.3.3.1 Requirements Management

Requirements definition and requirements management are critical to the success of projects. Part of requirements definition or formation is to ensure that all requirements are SMART, that is, that they are Specific, Measurable, Achievable, Relevant, and Traceable.[28] However, as shown in figure 3.3.3.1-1, the instruments cited problems in all of these areas. Percentages shown in the graph are based on the population of instruments that reported requirements management problems. Not only were the requirements not defined and not clearly communicated, but 47% of the instruments reported that the requirements were not defined early enough. The general workforce had a similar response. They reported that neither performance requirements or specifications (42%) nor technical interfaces (36%) were well defined prior to PDR.

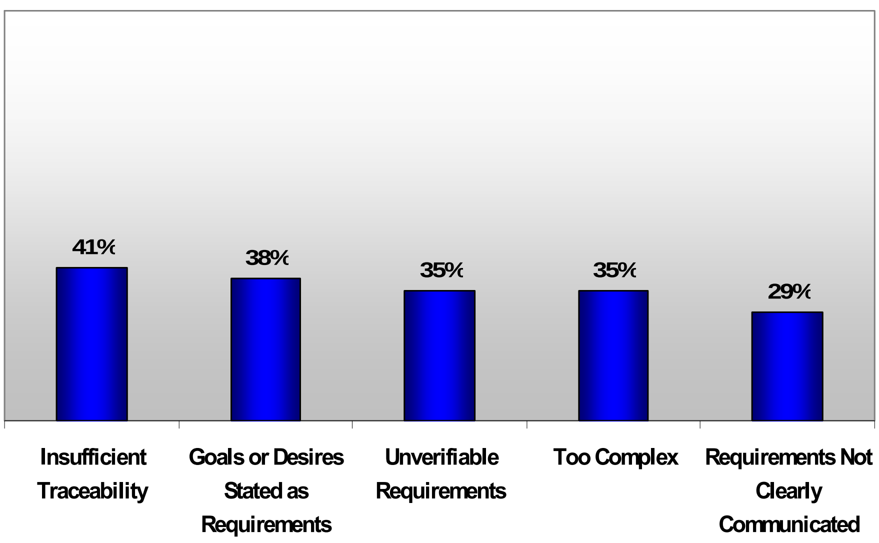


Figure 3.3.3.1-1. Requirements Management Issues Reported by Instruments

The issues that had the largest impact were related to requirements complexity and traceability. Instruments that reported the requirements were too complex were 1.6 times as likely to have 25% or more cost overruns and 2 times as likely to have schedule delays of 5 months or more. Instruments that reported that there was insufficient traceability were 1.4 times as likely to have 25% or more cost overruns and 1.9 as more likely to have schedule delays of 5 months or more. It was also interesting to note that half of the challenged instruments reported these as problems, while none of the successful instruments reported these problems.

3.3.3.2 Requirements Changes

The second area of systems engineering that proved to be a problem for instrument developments was changing requirements, as shown in figure 3.3.3.2-1. Percentages shown in the graph are based on the population of instruments that reported problems in a particular area, e.g., changes in requirements or requirements management problems. Although at least half of the instruments reported that requirements were all or mostly defined prior to PDR, 75% reported that approved design, requirements, or interfaces changed after PDR. In addition, 50% reported changes after CDR. In both cases, instruments that reported changing requirements were 1.8 times more likely to have design deficiencies that contributed to cost growth or schedule delays. Instruments that reported too many requirements changes or insufficient review of changes were 1.6 times as likely to have 25% or more cost overruns. Lastly, instruments that reported that implementation of changes were not timely were 1.5 times as likely to have 25% or more cost overruns and 1.6 times as likely to have schedule delays of 5 months or more.

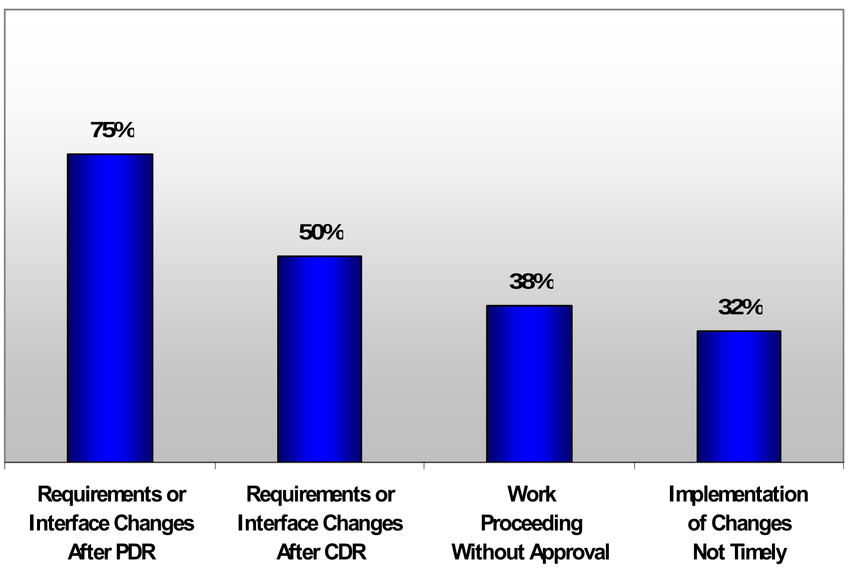


Figure 3.3.3.2-1. Requirements Changes Issues Reported by Instruments

3.3.3.3 Project Reviews

NASA projects have two common phases: Formulation and Implementation. Within each of these main phases are lifecycle phases (Pre-Phase A, Phase A, Phase B, etc.). Progression from one lifecycle phase to the next is marked by Key Decision Points (KDPs). At these KDPs, management examines the progress to date and the resources needed and risks associated with proceeding to the next phase.[29] One vital input necessary for these KDPs is the technical progress. This information is provided via technical or project reviews.

At NASA, Requirements, Design, and Test (Pre-Environmental) reviews are generally more formal reviews that have a review board, a process for submitting and closing actions, and involve the entire project. Conversely, peer, tabletop, and some test reviews are typically less formal and include the lead designer or engineer and a few cognizant engineers (peers). When asked how helpful these various reviews were, the instruments reported overwhelmingly that the less formal peer or tabletop reviews were very helpful (figure 3.3.3.3-1). Less than one third felt that Design or Requirements Reviews were very helpful.

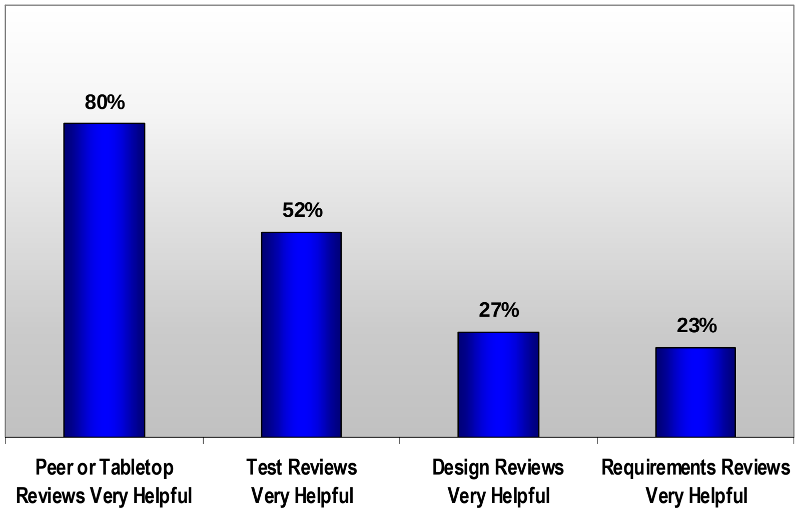


Figure 3.3.3.3-1. Effectiveness of Reviews

As far as meeting the success criteria at the formal reviews, 53% of the instruments reported that they held at least one delta review throughout the project. The general workforce also reported that not meeting the objectives in requirements reviews (32%) and design reviews (53%) was a problem. Challenged instruments were 3.2 times more likely to hold a delta review. The instruments that held a delta review were 1.9 times more likely to have schedule delays of 5 months or more, 1.9 times more likely to have design deficiencies that contributed to cost growth or schedule delays, and 2.5 times more likely to have workmanship and or technical problems that contributed to cost growth or schedule delays.

3.3.3.4 Risk Management

Risk management is a structured approach to managing uncertainty. Once risks are identified, they are typically assessed based on their likelihood of occurrence and consequence or impact if they were to be realized. Strategies are then developed to manage and/or mitigate them. Effective risk management requires the timely application of resources: people, money, schedule, and technical. However, two of the top risk management problems reported by instruments are related to a lack of resources (see figure 3.3.3.4-1). Percentages shown in the graph are based on the population of instruments that reported problems with risk management. 65% of the instruments indicated that they lacked resources to implement mitigation plans and 50% indicated that they lacked resources to analyze all identified risks. Instruments that had poor cost and schedule performance (i.e., challenged instruments) were 5 times more likely to report a lack of resources to implement risk mitigation plans. Furthermore, instruments that reported this as a problem were 1.6 times more likely to have 25% or more cost overruns and 1.4 times more likely to have schedule delays of 5 months or more.

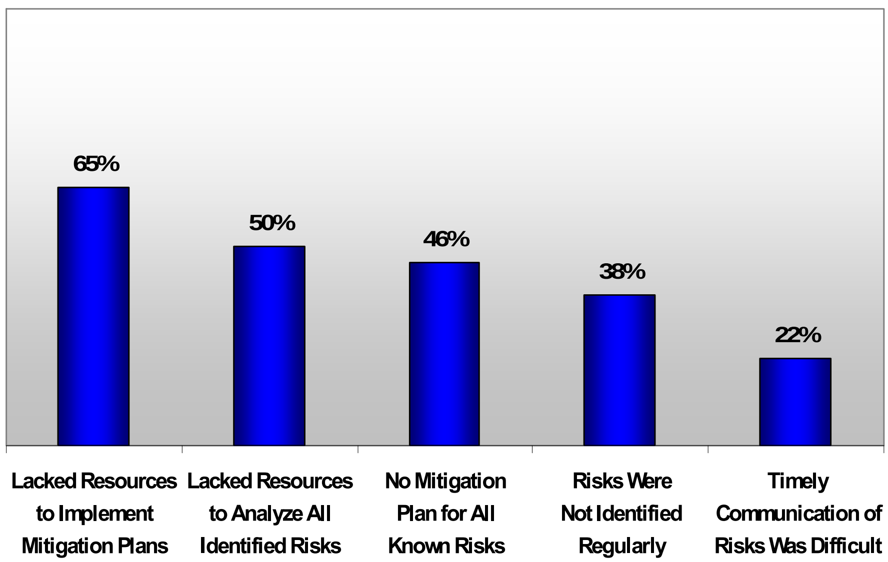


Figure 3.3.3.4-1. Risk Management Issues Reported by Instruments

The third risk management problem cited by instruments was the lack of mitigation plans for known risks. Challenged instruments were 1.8 times more likely to cite this as a problem than successful instruments. The remaining two issues involve timeliness of risk management. 38% of the instruments reported that risks were not identified regularly and 22% indicated that timely communication of risks was difficult. These instruments were 1.5 to 1.9 times more likely to have schedule delays of 5 months or more.

3.3.3.5 Configuration Management

The last area involves configuration management or change control. To prevent conflicting or unattainable requirements, two things need to occur. First, there must be constant communication among members of the project team. Second a process must be in place to maintain configuration control of the instrument hardware, software, and documentation.[25] Configuration management problems were reported by 63% of the instruments. Approximately one third of those instruments reported that configuration management was not implemented early enough. A little over half reported that configuration management required more support than needed or anticipated. In addition, 42% of the instruments reported that changes were not clearly communicated and that disposition of changes was not timely. Instruments that reported configuration management problems were 1.8 times more likely to have design deficiencies that contributed to cost growth or schedule delays.

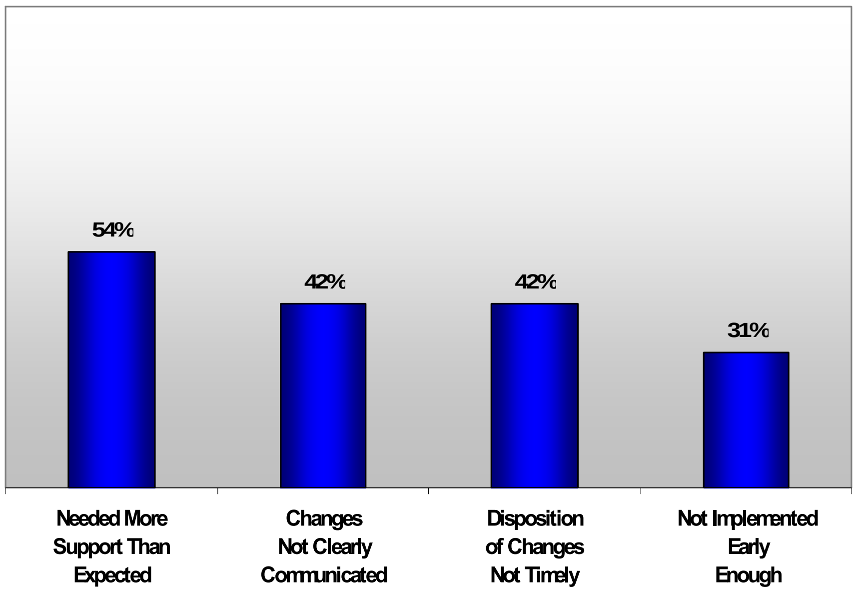


Figure 3.3.3.5-1. Configuration Management Issues Reported by Instruments

3.3.3.6 Relevant Independent Research

Systems engineering is an integrated discipline that strives for a balanced design that meets requirements, in the face of opposing interests and constraints. The systems engineering challenges identified previously by the instruments and the general workforce, affect the process of ensuring that the instrument team not only "gets the design right to meet the requirements, but that they get the right design". [3]

In addition to the data collected via the surveys, the independent research also addresses similar systems engineering issues throughout the instrument development's lifecycle. In one study, the NASA's Langley Research Center TMC team's evaluation of the proposals for PI-led science missions identified concerns about the systems engineering plans resulting in major weaknesses in 27% of the proposals. The following concerns were also identified in systems engineering leading to major weaknesses:

1. An incomplete flow-down of the science requirements to the instruments, payload accommodations, and flight systems;

[3] *Systems Engineering Handbook Rev1*, NASA/SP-2007-6105, Pp 3.

2. An unconvincing plan for how systems engineering responsibilities will be executed across the entire project; and
3. Whether the project implementation plan provided for adequate resources to successfully accomplish systems engineering.[9]

The first concern relates to insufficient traceability as discussed in section 3.3.3.1.

One source reported that systems requirements needed to be clearly traceable back to the science requirements and down to instrument and satellite requirements. Systems requirements must be clearly derived from science requirements, then rigorously documented and configuration controlled.[15] This also relates to insufficient traceability as discussed in section 3.3.3.1.

A report on acquisition of National Security Space Programs stated that: "Requirements growth is a dominant driver of cost increases and schedule delays. Prior to Program initiation, there is a growth in number and scope of key performance parameters, and ineffective systems engineering assessment of requirements impact. During Program Implementation, there is ineffective control of requirements change, and ineffective systems engineering assessment of impact of changes to requirements, thereby increasing risk". [4] This relates to the requirements changes issues as discussed in section 3.3.3.2.

Another source addressed one of systems engineering functions, i.e., risk management and stated that: "Greater attention needs to be paid to risk identification and management. Risk management should be employed throughout the life cycle of a project, much the way cost, schedule, and content are managed. Risk, therefore, becomes the "fourth dimension" of project management-treated equally as important as cost and schedule". [5] This relates to the risk management issues as discussed in section 3.3.3.4.

In summary, requirements definition, design, and flow down are essential for a successful instrument development. The flow down of requirements from the mission objectives and their definition for the flight design occur during the formulation phase. The process culminates in a set of instrument system requirements established prior to PDR. The instrument team develops the flight hardware based on these requirements and technical interfaces. They determine the complexity of the instrument design and how stable these requirements remain during the development effort. As expected, this systems engineering function has a significant impact on the resulting technical progress, as well as on the overall cost and schedule performance.

[4] Young, T., *Report of the Defense Science Board/Air Force Scientific Advisory Board Joint Task Force on Acquisition of National Security Space Programs*, pp 64

[5] *Report on Project Management in NASA by the Mars Climate Orbiter Mishap Investigation Board*, pp 7.

3.3.4 Instrument Management Issues

The fourth overarching theme encompasses instrument management issues. The instrument manager provides the programmatic leadership for the instrument development and acts as the interface between the project and the instrument team. Instrument management involves the planning, organizing, and managing of resources to successfully meet the project requirements and deliverables. When any of these areas are compromised, cost, schedule and technical performance is adversely impacted.

3.3.4.1 Organizational Interface Issues and Impact

As shown in figure 3.3.4.1-1, 61% of the instrument developments involved two or more partners in the design and fabrication of the instrument. Overall, 88% of the instruments reported problems with organizational interfaces in the areas of communication (57%), lines of authority (54%), and staffing agreements (46%). Multiple instruments reported that lines of communication were either poorly defined or were not enforced. They also reported that there was poor communication due to language barriers or physical separation. Instruments that reported problems with lines of communication were 2.3 times more likely to have schedule delays of 5 months or more.

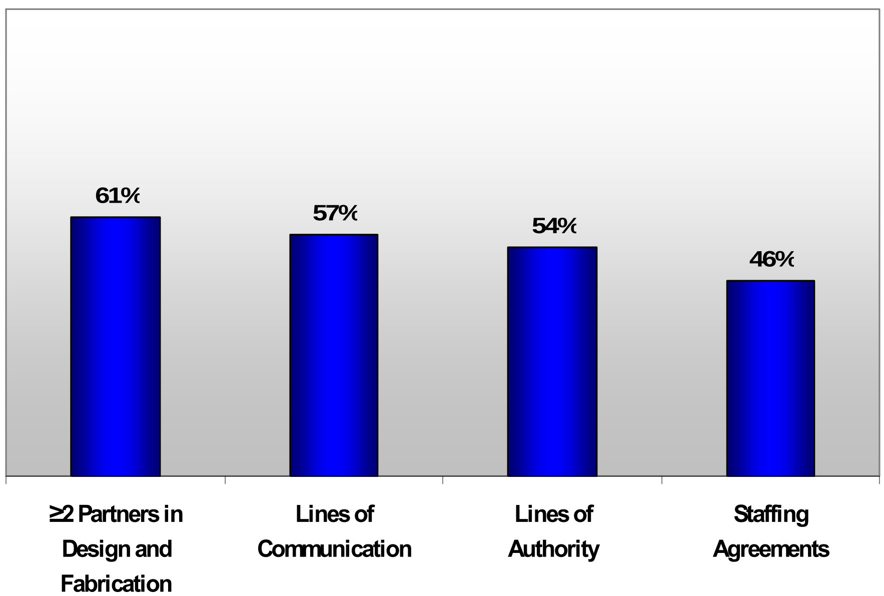


Figure 3.3.4.1-1. Organizational Interface Issues Reported by Instruments

About half of the instruments reported problems with lines of authority. Specific problems cited include: multiple customers duplicating efforts; poor definition or conflicting lines of authority; lack of authority over staff; and lack of contractual authority. The instruments that experienced problems with lines of authority were 1.7 times more likely to have schedule delays of 5 months or more.

The last organizational interface problem reported by instruments were problems with staffing agreements. Several instruments reported understaffing due to commitments to other projects. These instruments were 1.3 times more likely to have 25% or more cost overruns.

3.3.4.2 Subsystem Management Issues and Impact

Figure 3.3.4.2-1 shows subsystem management problems reported by the instruments. The percentages shown in the graph are based on the population of instruments that reported problems in a particular area, e.g., problems with budget or schedule management. More than half of the instruments reported issues with subsystem management and ownership of their budgets and schedules. Instruments that reported their schedules were not managed efficiently at the subsystem level were 1.2 times more likely to have 25% or more cost overruns and 1.6 times more likely to have schedule delays of 5 months or more. Instruments that reported their budgets were not managed efficiently at the subsystem level were 1.4 times more likely to have 25% or more cost overruns and 1.7 times more likely to have schedule delays of 5 months or more.

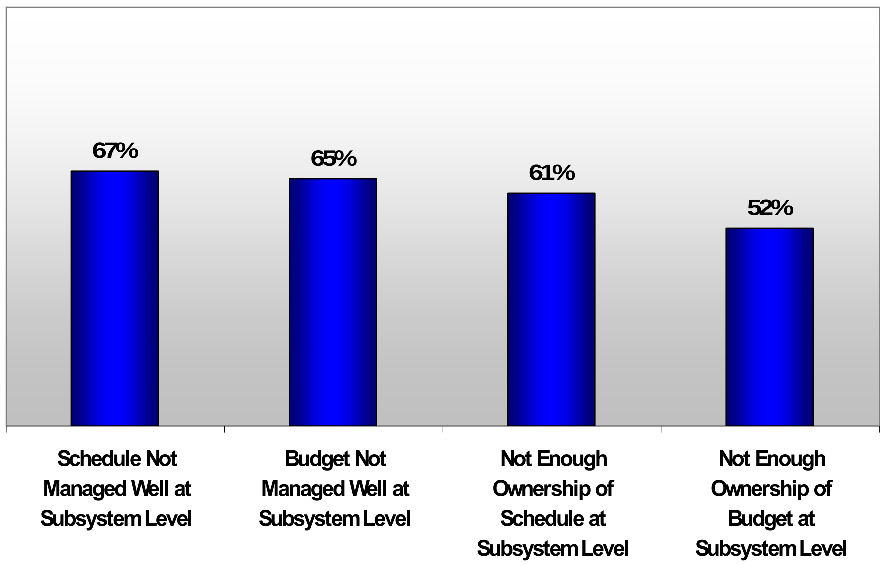


Figure 3.3.4.2-1. Subsystem Management Issues Reported by Instruments

Instruments that reported that there was not enough schedule ownership or accountability at the subsystem level were 1.7 times more likely to have 25% or more cost overruns and 1.4 times more likely to have schedule delays of 5 months or more. Instruments that reported that there was not enough budget ownership or accountability at the subsystem level were 1.4 times more likely to have 25% or more cost overruns and 1.7 times more likely to have schedule delays of 5 months or more.

3.3.4.3 Programmatic Reserve Authority Issues and Impact

Half of all instruments and two thirds of the challenged instruments reported that the project kept all of their instrument reserves. These instruments were 1.4 times more likely to have 25% or more cost overruns and 1.3 times more likely to have schedule delays of 5 months or more. In addition, 40% of all instruments and 54% of the challenged instruments had less than 20% planned for budget reserves. These instruments were twice as likely to have schedule delays of 5 months or more.

3.3.4.4 Timeliness Issues and Impact

The instruments reported various issues with timeliness in requirements, configuration, schedule, budget, and risk management (refer to figure 3.3.4.4-1). Percentages shown in the graph are based on the population of instruments that reported problems in a particular area. Requirements were not defined early enough was reported by 47% of the instruments, while 32% reported too long of a lag between proposed requirements changes and approval. The instruments that reported these implementation issues were 1.5 times more likely to have 25% or more cost overruns and 1.6 times more likely to have schedule delays of 5 months or more. The challenged instruments were 4.1 times more likely to report this problem than successful instruments. The instruments that reported their integrated schedule was not developed early enough were 1.7 times more likely to have schedule delays of 5 months or more. The instruments that reported that the integrated budget was not developed early enough were 1.4 times more likely to have 25% or more cost overruns and 1.7 times more likely to have schedule delays of 5 months or more. Lastly, the instruments that reported timely communication of risks across the team was difficult were 1.2 times more likely to have 25% or more cost overruns and 1.5 times more likely to have schedule delays of 5 months or more (challenged instruments were 2.7 times more likely to cite this as a problem).

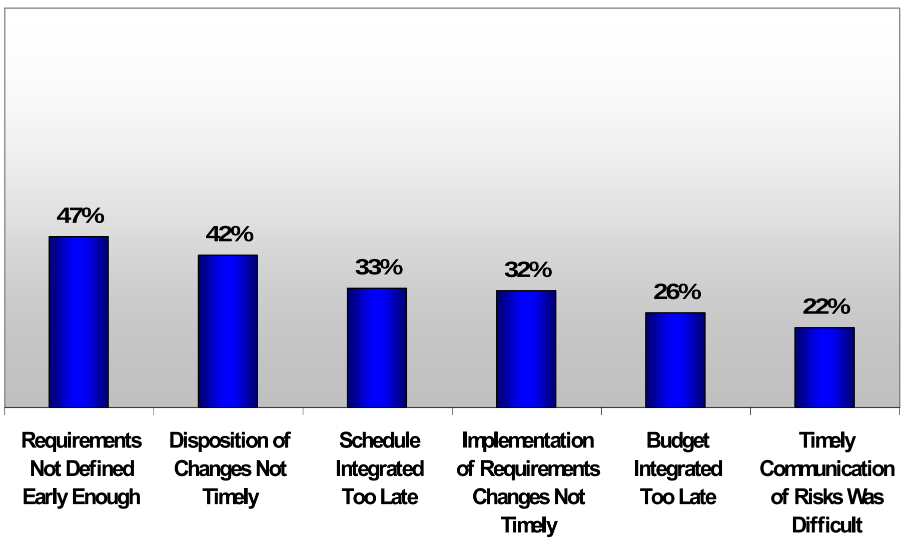


Figure 3.3.4.4-1. Timeliness Issues Reported by Instruments

3.3.4.5 *External Factors Issues and Impacts*

In addition to optimistic or unrealistic budget and schedule baselines, instrument developments had to contend with numerous external factors that affected cost and schedule performance (refer to figure 3.3.4.5-1). Percentages shown in the graph are based on the population of instruments that reported problems in a particular area, e.g., budget management, schedule management, etc. Of the instruments surveyed, 56% reported schedule changes were directed by external factors. The challenged instruments were 4.2 times more likely to cite this as a problem than successful instruments. The instruments that reported this problem were 1.5 times more likely to have 25% or more cost overruns and 1.2 times more likely to have schedule delays of 5 months or more. In addition, 41% of the instruments reported that the imposition of new programmatic scope such as new policy issuance, introduction of earned value management, changes in procurement strategy, etc. caused cost growth.

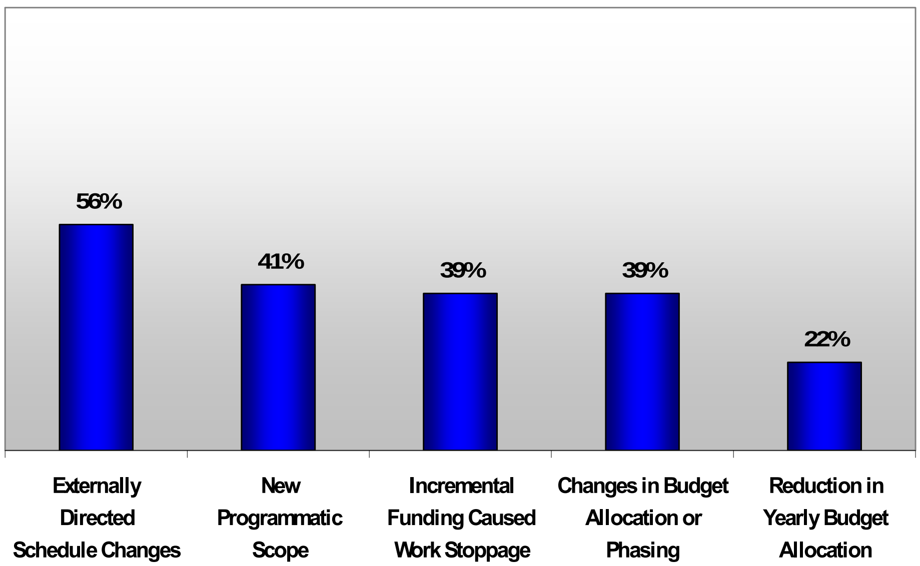


Figure 3.3.4.5-1. External Factors Issues Reported by Instruments

Furthermore, 39% of the instruments reported changes in budget allocation or phasing and 22% reported that the yearly budget allocation was less than what was planned. Challenged instruments were 4.5 times more likely to have changes in budget allocation or phasing. In addition, the instruments that reported this problem were 1.3 times more likely to have 25% or more cost overruns and twice as likely to have schedule delays of 5 months or more.

All of the instruments that received less money than was planned had schedule delays of 5 months or more. They were also 1.4 times more likely to have 25% or more cost overruns. Instruments that reported that incremental funding caused schedule delays or work stoppage were 1.3 times more likely to have 25% or more cost overruns and 1.7 times more likely to have schedule delays of 5 months or more.

3.3.4.6 *Relevant Independent Research*

The management challenges reported by the instruments and the general workforce hinder the instrument manager's ability to successfully deliver the instrument within technical, cost and schedule requirements. There were interface, subsystem management, and timeliness issues identified, which should have been within the instrument manager's control to solve. There were also external issues identified, such as control of the programmatic reserves, changes in program scope, and implementation of a new procurement strategy, which also led to cost growth and schedule delays.

Data from the surveys is supported by the independent research, which also addresses similar management issues throughout the instrument development's lifecycle.

A NASA Langley Research Center study identified issues in two management areas: management plans and project schedules, which resulted in major weaknesses in proposals. Common sources of major weaknesses within project management included:

1. Confusing organizational roles and responsibilities for the participating institutions or key individuals;
2. Unclear lines of authority within the project or between the project and the participating institutions;
3. Lack of demonstrated organization or individual expertise for the specific role identified; and
4. Low time commitments for essential members of the core management team.

These relate to the organizational interface issues as discussed in section 3.3.4.1.

Regarding the master schedules, one item of concern leading to major weaknesses included showing no margin or inadequate margin to address potential delays. This source also discussed the common reasons why proposals received a major weakness in cost, which highlighted issues with the reserve posture. These reasons were:

1. Deficient plan for the cost reserve (e.g., a reserve level below the requirement, reserves too low to cover cost threats identified during evaluation, and phasing of reserves in the funding profile too late to be useful);
2. Flawed basis of estimate for the reserve; and
3. Review team's inability to validate the cost estimate.[9]

These relate to the programmatic reserve authority issues as discussed in section 3.3.4.3.

A source reported that communication failures within the design team, formal or informal, often caused critical items to be overlooked later necessitating expensive fixes and workarounds.[3] This relates to the lines of communication issue as discussed in section 3.3.4.1.

In addition, a paper looked at recent NASA cost and schedule growth history, categorized the reasons for growth, and provided guidance for the proper cost and schedule reserves to be carried both at the program and project levels. The effective use of Earned Value Management (EVM) in some successful missions was also addressed as an early indicator of cost problems, thus facilitating timely application of resources to recover.[5] These relate to programmatic reserve authority issues and external factors issues as discussed in section 3.3.4.3 and 3.3.4.5, respectively.

In summary, most of these issues identified by the surveys are not new to the instrument manager and they seem to recur from one instrument development to another. Innovative approaches are required to better plan and manage instrument resources and to minimize the impact of the external factors, which impede the instrument development progress.

3.3.5 Testing Issues

An important phase of an instrument's development process is validation and verification. Validation requires demonstrating that the instrument will accomplish the intended mission and will meet the customer's needs and objectives. However, the goal of the verification process is to demonstrate that the instrument complies with all requirements.[22] Both areas usually involve testing in various configurations and under a series of "flight-like" conditions. Because system level verification and validation occurs late in the project life cycle, any problems encountered have the potential to erode schedule and budget reserve, as well as, impact delivery to the spacecraft. The following sections highlight issues related to test planning and implementation as well as factors contributing to test failures. Correlations to cost overruns and schedule delays will be discussed as well.

3.3.5.1 Test Planning Issues and Impact

Figure 3.3.5.1-1 shows the test planning issues reported by the instruments and the general workforce. Percentages shown in the graph are based on the population of instruments that reported problems in a particular area, e.g., lack of ETU, facilities issues, etc. 52% of the instruments reported that they did not build an Engineering Test Unit (ETU). All of those instruments had workmanship or technical problems that contributed to cost growth or schedule delays. The general workforce also reported that not having an ETU was a problem.

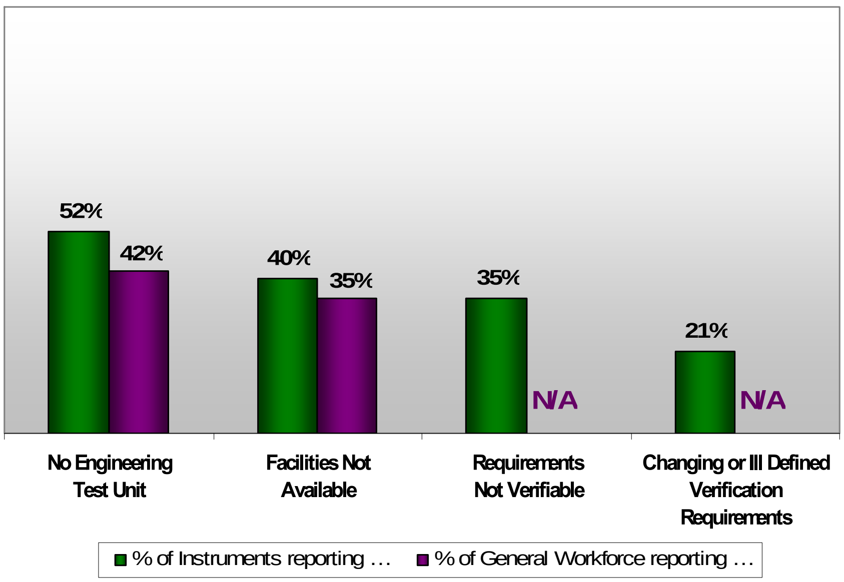


Figure 3.3.5.1-1. Issues with Test Planning as Reported by the Instruments and General Workforce

The second issue cited was the lack of availability of facilities as reported by 40% of the instruments. 35% of the general workforce reported problems with resources such as people or facilities conflict or unavailability. Instruments that reported this problem were 1.5 times more likely to have schedule delays of 5 months or more.

The two problems related to requirements definition or management were reported solely by the instruments. The instruments that reported requirements were unverifiable were 1.3 times as likely to have 25% or more cost overruns and 1.2 times more likely to have schedule delays of 5 months or more. This problem was also reported 1.8 times more often by the challenged instruments than the successful instruments. In addition, 21% of the instruments reported that verification requirements and methods were not well defined or were changing often. These instruments were 1.3 times more likely to have 25% or more cost overruns.

Lastly, 13% of the instruments reported inadequate planning for facilities and 46% of the general workforce reported that the instrument's test plan did not adequately account for actual resource needs. The instruments that reported this problem were 1.5 times more likely to have 25% or more cost overruns and 1.3 times more likely to have schedule delays of 5 months or more.

3.3.5.2 Test Implementation Issues and Impact

The percentages shown in figure 3.3.5.2-1 are based on the population of instruments that reported problems in a particular area, e.g., facilities issues, insufficient testing, etc. As shown in the graph, 67% of the instruments and less than one fourth of the general workforce reported facility issues during testing. The instruments that had problems with ground support equipment (GSE) were 1.3 times more likely to have 25% or more cost overruns and 1.9 times more likely to have schedule delays of 5 months or more. The instruments (46%) that reported testing took longer than anticipated were 1.8 times more likely to have 25% or more cost overruns and 1.6 times more likely to have schedule delays of 5 months or more. Almost half of the general workforce reported that not enough instrument or subsystem testing was performed. Both the instruments and general workforce reported that instrument tests were deferred to the spacecraft level and that some instruments did not “test as you fly.” Those instruments that did not test in the flight configuration were twice as likely to have schedule delays of 5 months or more.

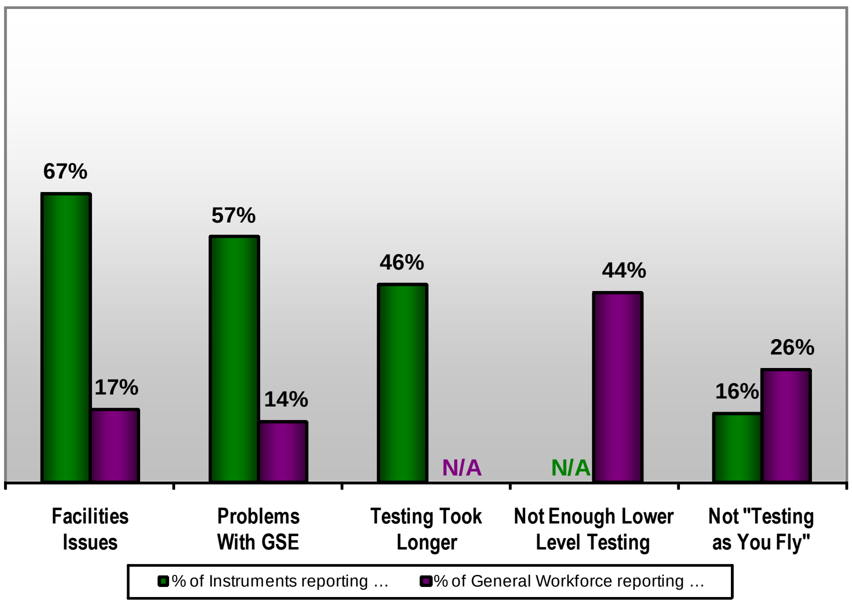


Figure 3.3.5.2-1. Issues with Test Implementation as Reported by the Instruments and General Workforce

3.3.5.3 *Test Failures and Impact*

Test failures was the number one problem area reported by the instruments (95%). Figure 3.3.5.3-1 shows the top four contributing factors. The first, which was cited by 82% of the instruments, is workmanship and/or technical problems. Those that had workmanship problems were 1.5 times more likely to have schedule delays of 5 months or more.

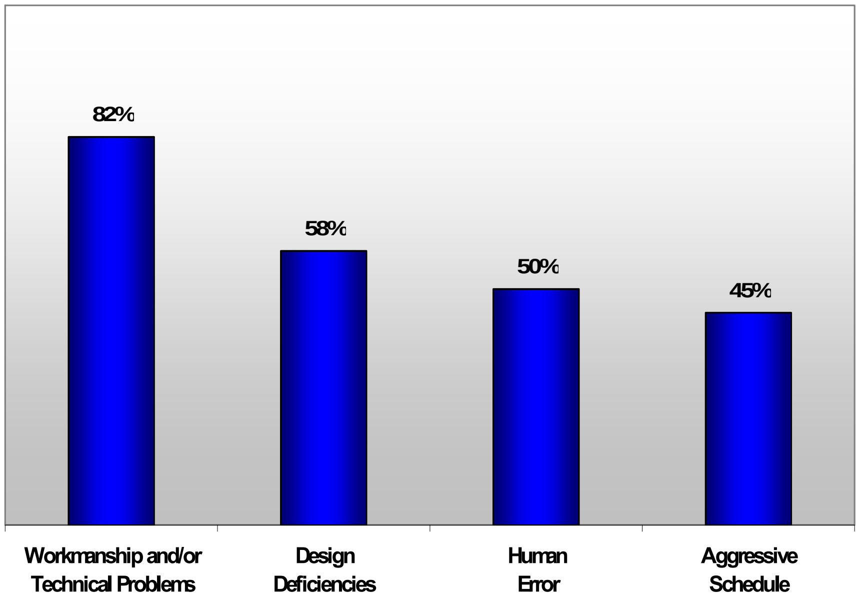


Figure 3.3.5.3-1. Top Contributing Factors to Test Failures

In addition, 58% of the instruments reported design deficiencies as contributing to test failures. These instruments were 1.5 times more likely to have 25% or more cost overruns and 2.3 times more likely to have schedule delays of 5 months or more. The instruments that reported human error (50%) as causing test failures were 1.5 times more likely to have 25% or more cost overruns and schedule delays of 5 months or more.

Finally, the instruments that reported having an aggressive schedule (45%) were 1.4 times more likely to have schedule delays of 5 months or more.

3.3.5.4 Cost/Schedule Growth During Testing

The data indicated that 95% of the instruments reported they experienced cost growth during testing. 92% reported that they experienced schedule delays during testing. Although there were specific factors that were reported to cause one or the other, all factors shown in figure 3.3.5.4-1 correlated with both cost overruns and schedule delays.

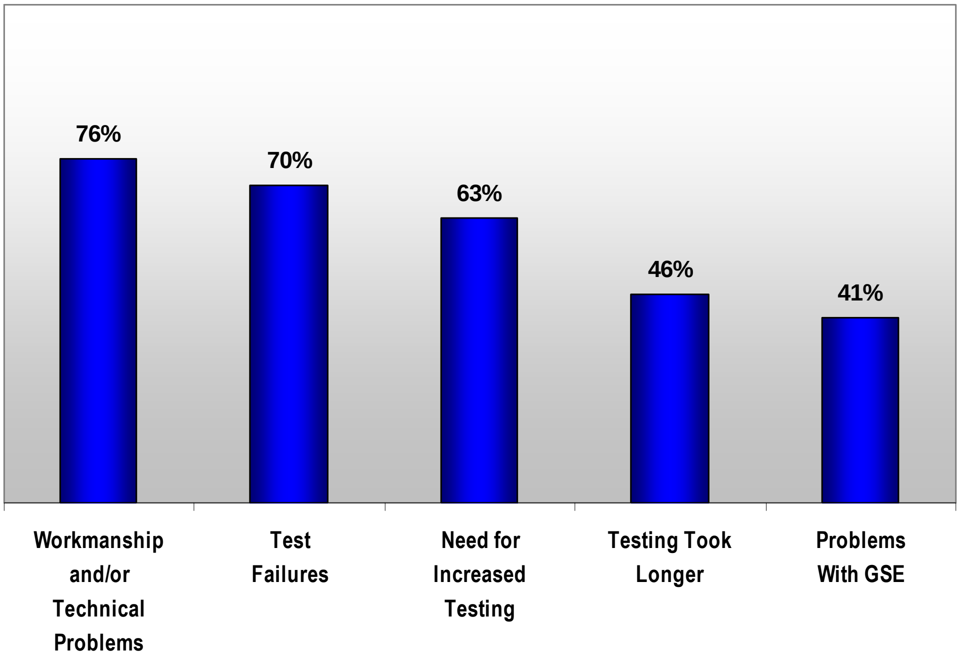


Figure 3.3.5.4-1. Factors that Caused Cost Growth or Schedule Delays During Testing

In particular, 76% of the instruments reported that workmanship and/or technical problems caused schedule delays. Those instruments were 1.6 times more likely to have 25% or more cost overruns and 3 times more likely to have schedule delays of 5 months or more.

Furthermore, 70% of the instruments reported that test failures caused schedule delays. These instruments were 1.6 times more likely to have 25% or more cost overruns or schedule delays of 5 months or more.

Another factor that was reported to have contributed to schedule delays was testing taking longer than expected. These instruments were 1.8 times more likely to have 25% or more cost overruns and 1.7 times more likely to have schedule delays of 5 months or more.

The last factor that contributed to schedule delays was problems with ground support equipment (GSE). These instruments were 1.5 times more likely to have 25% or more cost overruns and twice as likely to have schedule delays of 5 months or more.

The one factor that was reported to have contributed to cost growth was the need for increased testing. These instruments were twice as likely to have 25% or more cost overruns and 1.7 times more likely to have schedule delays of 5 months or more.

3.3.5.5 Relevant Independent Research

The challenges reported by the instruments and the general workforce covered all aspects of testing, from planning to implementation, in addition to key factors causing cost growth or schedule delays. As stated in section 3.3.5.3, the number one problem reported by the instruments was test failures.

Data from the surveys is supported by the independent research, which also addresses similar testing issues throughout the instrument development's lifecycle. A NASA Langley Research Center study identified insufficient integration and test program, including an end-to-end verification test, as a common cause for major weaknesses in proposals.[9] This relates to poor test planning as discussed in section 3.3.5.1.

A source stated that: "the proposed use of non-standard facilities for flight hardware should be very carefully weighed during the planning phase of a project or task. … Damage and subsequent repair to flight instruments or subsystems is costly in both schedule and dollars and could have severe project and mission impact."[6] This relates to unavailability of facilities as discussed in section 3.3.5.1.

Another source stated that the test facilities may deteriorate between periods of use and may not be fully ready for the next major test program. Lack of full readiness may be especially risky when testing near the limit of the environmental equipment capability, or with resource-constrained projects that may lack the time and funding to correct deficiencies.[12] This relates to facility issues during the implementation phase as discussed in section 3.3.5.2.

A report stated that: "After launch of a spacecraft, an electromagnetic interference/electromagnetic compatibility (EMI/EMC) interference affecting science data was noted in the instrument data. The interference was subsequently attributed to the transmitters and was due to the inadequate instrument shielding. The problem was aggravated by a malfunction in the spacecraft antenna. … More time could have been allocated for EMI/EMC system-level testing. It is important to test all flight hardware in as near flight conditions as possible to avoid on-orbit failures".[7] This relates to both technical problems and aggressive schedule as discussed in section 3.3.5.3.

Another paper identified instrument technical problems as one of the specific causes why a significant number of missions had experienced cost and schedule growth. "Typically an instrument is on the critical path for development, and any delay in the instrument results in a "marching army" cost that includes integration and test and other personnel."[8] This relates to workmanship and/or technical problems as discussed in section 3.3.5.3.

A study stated that the NASA MIB identified schedule pressure "as the cause for the inadequate testing of a late change to the navigation logic's gain setting". This change occurred close to the planned launch date and the pressure to maintain the launch date drove the decision to forego testing. Had this testing occurred, the problem with the lower gain setting would have been found. The use of the incorrect gain control was one of the causes of the mission failure.[23] This is another example of aggressive schedule as a contributor to test failures.

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[6] *Facility Failure During Testing of the Galileo Near Infrared Mapping Spectrometer (NIMS)*, NASA Engineering Network Lessons Learned Article, pp1.

[7] Crosby, D., *AMSU-B EMI/EMC System Level Testing,* NASA Engineering Network Lessons Learned Article, pp1.

[8] Emmons D., et al., *Using Historical NASA Cost and Schedule Growth to Set Future Program and Project Reserve Guidelines*, IEEE Aerospace Conference, Big Sky, Montana, March 3-10, 2007.

In summary, most of the testing issues occur during the instrument level integration and test phase and the instrument manager can mitigate these issues with proper planning during the instrument development phase. Early instrument-level testing will provide insight into any issues that may otherwise only be observed at the later stages of integration, where it becomes costly to fix.

3.3.6 Discussion

An evaluation of the data from the Instrument Survey, the General Workforce Survey, and the Independent Research resulted in five Study themes: staffing, acquisition, systems engineering, instrument management, and testing issues. Common issues or threads, and their impacts, were examined within each of the themes. These threads, which are indentified in the table below, were then evaluated across all of the themes to develop the overall study findings and recommendations, which are discussed in section 4.

Table 3.3.6-1. Summary of Threads

Theme		Thread	Supporting Information
Staffing (ST)	ST-1	Instrument leadership issues	• Inexperienced leadership • Difficulty finding expertise or experience • >2 changes in leadership positions
	ST-2	Instrument teams are understaffed	• Team members supporting multiple projects • Project teams understaffed • Attrition • Lack of project support (e.g., configuration, risk, schedule, and budget management)
	ST-3	Difficulty acquiring critical skills	• Critical knowledge limited to a few individuals • Difficulty finding expertise • Lack of Safety & Mission Assurance personnel expertise
Acquisition (AQ)	AQ-1	Insufficient resources to successfully develop instruments	• Optimistic/Unrealistic initial budget and schedule estimates • Insufficient cost cap and allocated schedule
	AQ-2	Supply chain issues	• Parts, subsystems, or instrument level procurement issues • Component supplier issues
Systems Engineering (SE)	SE-1	Requirements management problems	• Requirements management problems • Requirements or specifications not clearly communicated • Work proceeding at risk ahead of change/waiver approval • Implementation of changes not timely
	SE-2	Requirements formulation issues	• Insufficient requirements traceability • Goals or desires stated as requirements • Requirements too complex • Requirements unverifiable
	SE-3	Issues with requirements changes	• Design, requirements or interface changes occurring after PDR • Design, requirements, or interface changes occurring after CDR
	SE-4	Risk management resource issues	• Lack of resources to manage risks • Risks not identified regularly • Mitigation plans not developed for all known risks
	SE-5	Review effectiveness	• Requirements Reviews not considered helpful • Objectives not met in requirements reviews

Table 3.3.6-1. Summary of Threads (continued)

Theme		Thread	Supporting Information
Instrument Management (IM)	IM-1	Issues with instrument reserves	• Lack of cost/schedule reserve authority • Insufficient planned budget reserves
	IM-2	External factors	• Externally directed schedule changes • Changes in budget allocation or phasing • Incremental funding causing schedule delays or work stoppage
	IM-3	Issues with lines of communication or authority	• Problems with lines of authority
	IM-4	Issues with schedule or budget management	• Schedules and budgets not managed well at subsystem level
Testing Issues (TI)	TI-1	Test issues	• Unverifiable requirements • Testing took longer • Aggressive schedule • Test failures • Workmanship or technical problems • Problems with GSE or special test equipment

4 FINDINGS AND RECOMMENDATIONS

While performing a systematic review and assessment of 41 instruments across NASA, NOAA, and DoD, the NASA Instrument Capability Study team found that there were both overarching factors, as well as process issues that are impacting instrument development. A correlation was made between the issues indentified and an increased likelihood of schedule delays, cost overruns, and technical problems. The Study team's analysis has been rolled up into the following findings:

Finding 1: Instrument developments lack the resources and authority to successfully manage to cost and schedule requirements. *(Cross-reference to theme threads shown in table 3.3.6-1: ST-2, TI-1, SE-4, IM-1, IM-3, and IM-4.)*

One of the instruments' staffing resource issues is a lack of project support to perform configuration, schedule, or budget management. Instruments also reported that they lacked resources to manage risks and that schedules and budgets were not being managed well at the subsystem level. Insufficient schedule reserve was a problem as well, given that instruments reported significant schedule delays due to problems encountered during testing. Lastly, instruments that held less than 20% budget reserves were more likely to have schedule delays of 5 months or more.

As for authority issues, instruments reported problems or confusions with lines of authority. Additionally, the lack of cost and schedule reserve authority was shown to correlate with increased likelihood of cost overruns or schedule delays.

To address the problems discussed above, the Study team made the following recommendation:

Table 4-1. Finding 1 Recommendations and Rationale

Recommendation	Rationale
1. Implement changes to policy to define and elevate instrument management requirements and authorities in a manner similar to project-level management.	Instrument developments are uniquely complex, often one-of-a-kind, and, as such, require a higher level of visibility, authority, and support than normal spacecraft subsystems.
2. Assign NASA instrument managers full authority and responsibility to manage their cost and schedule reserves and hold them accountable.	Transition of authority to the lower levels is necessary to permit informed management and mitigation of risks before they turn into more expensive problems.
3. Require 30% to 50% cost reserves for instrument developments (>$10M) to account for the fact that most instrument developments are highly complex, single builds. 4. Require 1½ to 2 months per year of schedule reserve for instrument developments (>$10M). 5. Require dedicated level of support staff (configuration management, schedule management, risk management and budget management) for instrument developments (>$10M).	The typical rule of thumb of 25% cost reserve and 1 month per year schedule reserve does not appear to be sufficient for instrument developments. This is corroborated by the data which indicated that ~70% of the instruments reported 25% or more cost overruns and ~60% of the instruments reported schedule delays of 5 months or more.

Finding 2: Instrument developments are lacking the critical skills, expertise, or leadership to successfully implement these unique (one-of-a-kind), high technology developments. *(Cross-reference to theme threads shown in table 3.3.6-1: ST-1, ST-2, and ST-3.)*

The Study highlighted numerous staffing problems that fell into two primary areas – lack of critical skills or lack of expertise. The exact issues cited were: (1) critical knowledge being limited to a few individuals, (2) difficulty finding technical expertise or experience, (3) problems with staffing levels, and (4) more than two changes in leadership positions. These issues may be compounded in the future since, as reported in a previous section, 60% of the Federal Workforce will be eligible for retirement in the year 2016.

As shown in table 4-2, the Study team has made three recommendations to address these concerns. Please note, however, that although the survey results underscore broader issues relating to attracting and retaining critical skills or expertise, the team did not make any recommendations to explicitly address these issues. They are being otherwise addressed by the NASA National Recruitment Initiative.

Table 4-2. Finding 2 Recommendations and Rationale

Recommendation	Rationale
1. Expedite the planned enhancement of the NASA Engineering Network People, Organization, Project, Skills (POPS) expertise locator to enable instruments to address critical skills shortages by drawing upon personnel from other NASA centers. 2. Add capability to the POPS locator to include data sources external to the NASA workforce. 3. Require the addition of a deputy instrument manager position (similar to a deputy project manager), for instrument developments with a budget >$10M.	Expediting the POPS expertise locator enhancement will allow instrument projects to locate critical skills in the near term mitigating staffing issues, which is one of the top five problems reported in this Study. POPS allows instruments to draw from a wider pool of potential expertise. Given the complexity and scope of instrument developments, the addition of a deputy instrument manager position is warranted. This position creates a mechanism for transfer of corporate knowledge, training and mentoring, and provides critical support to the instrument manager. Finally, it ensures continuity, should leadership transitions occur.

Finding 3: There are significant process problems in the area of requirements formulation, reviews, and management. *(Cross-reference to theme threads shown in table 3.3.6-1: TI-1, SE-1, SE-2, SE-3, and SE-5.)*

NASA has well-defined processes and procedures in place to facilitate good requirements formulation to ensure that the final product meets the intended goals and objectives. However, the Study team identified certain weaknesses in the implementation of the requirements' management process. Specific issues identified were as follows:

- Problems with requirements formulation/definition – Instruments reported that (1) goals or desires were stated as requirements, (2) requirements were too complex or unverifiable, and (3) there was insufficient traceability up to higher level requirements. Two-thirds of the instruments reported that design and performance requirements were all or mostly defined and approved prior to PDR. However, three-quarters of the instruments reported that approved requirements changed after PDR and half reported that they changed after CDR. This suggests that the requirements were not defined well and that there may be a problem with the review/approval of the requirements; which leads to the next issue identified.

- Problems with the requirements review – The data related to requirements reviews was concerning. Less than one-fourth of the instruments reported that requirements reviews were very helpful. In addition, the general workforce reported that objectives were not being met in the requirements reviews. More than one-fourth of the instruments did not hold a requirements review and 57% did not hold one at the instrument subsystem level.

- Problems with requirements management – 83% of the instruments and 43% of the general workforce indicated that there were problems with requirements management. All of the instruments that cited requirements management problems had design deficiencies that contributed to cost growth or schedule delays. Conversely, all of the instruments that did not report requirements management problems did not have design deficiencies.

The Study team recommends that policy changes be implemented that strengthens the execution of the instrument requirements management processes. The details of this recommendation are shown in table 4-3:

Table 4-3. Finding 3 Recommendations and Rationale

Recommendation	Rationale
1. Require NASA instrument team leadership to take requirements formulation/management training, e.g., "Requirements Development and Management (APPEL-REQ)", prior to requirements development. 2. Require instrument teams to conduct Peer Reviews of requirements (for each instrument subsystem), in preparation for instrument SRRs. 3. Require draft mission Level 1 and 2 technical requirements to be controlled and provided to instrument managers prior to the instrument SRR. Also, notify instrument managers of any changes to the draft requirements so that impact assessments can be performed.	In order to fix the requirements problems reported in the Study, a wide range of recommendations should be implemented. These recommendations include a greater emphasis on training to provide instrument teams a better understanding of how to formulate and manage requirements. The recommendations also provide an improved requirements review process to account for the fact that instrument SRRs occur much earlier than mission SRRs which often leads to requirements changes, as well as traceability issues. Finally, a recommendation is added to provide instruments with top level requirements early in formulation to allow for a more thorough requirements development and management process.

Finding 4: Unrealistic caps, overly optimistic estimating, and externally directed changes correspond to a significant increase in the likelihood of overrunning cost and schedule. *(Cross-reference to theme threads shown in table 3.3.6-1: AQ-1 and IM-2.)*

The survey results, as well as the independent research, illustrated that there is a definite problem with unrealistic cost/schedule caps and estimating. Furthermore, instrument development is hindered by externally directed changes to budgets and schedules. A concerted effort needs to be made to improve cost and schedule estimates from proposal development to evaluation by the government. In addition, cost and schedule estimates should be reviewed prior to confirmation of the instrument project. Table 4-4 shows the team's recommendations for improving cost estimating credibility and budget management oversight down to the instrument level.

Table 4-4. Finding 4 Recommendations and Rationale

Recommendation	Rationale
1. Develop an Agency-level historical cost and schedule database of instruments to provide information that would allow for higher fidelity cost caps. 2. Review cost credibility evaluation and scoring criteria for accuracy and flow-down to the proposal selection process (for use by Technical Management and Cost (TMC) or project Source Evaluation Board (SEB)).	The costing database will be useful in: establishing higher fidelity cost caps; evaluating government and contractor instrument proposals; and assessing progress during implementation. Furthermore, a data exchange between NASA, NOAA, and DoD on instrument development cost data would allow for a more thorough data set. Improved cost credibility criteria support a more robust and thorough source selection.
3. Establish a Peer Review prior to PDR for instruments >$10M to assess budget and schedule baseline credibility and increase the emphasis on cost and schedule assessment at PDR.	Adding a budget and schedule baseline credibility Peer Review prior to PDR will increase confidence going in to the Confirmation Review.
4. Ensure that instrument managers are made aware of externally driven changes in a timely manner and afforded the opportunity to discuss any impacts prior to implementation of changes.	Early communication of externally driven changes (e.g., budget or schedule changes) down to the instrument level minimizes the impact to the instrument development.

Note: The NICS team did not develop a recommendation for cost estimating problems since this issue is currently being addressed by a multi-Agency team (The Space Systems Cost Analysis Group, co-chaired by NASA). This group is sponsoring a Baseline Realism Team.

Finding 5: NASA needs a method to continue answering basic questions pertaining to the instrument development process to identify any emerging or persistent issues.

This Study has established a foundation for objective instrument development analysis. The intent of these recommendations is to improve future instrument developments by providing a mechanism for data collection, on-going analysis, and development of corrective actions.

Table 4-5. Finding 5 Recommendations and Rationale

Recommendation	Rationale
1. Require **all** instrument managers to take the survey upon delivery of their instrument. 2. Maintain survey results in a historical database.	The aggregated data could provide the Agency information regarding trends, persistent issues, and emerging issues.

Concluding Remarks

While the focus of this study was to determine whether or not there are global issues impacting instrument development, the Study team found areas where no corrective action is needed. Examples of this include: S&MA requirements, which were reported as appropriate; and informal reviews, which were viewed favorably by the survey respondents. The NASA Instrument Capability Study has established a foundation for objective instrument development analysis. A strict process was followed to ensure integrity and confidentiality across all Study elements. Quantitative data has been collected and analyzed, which indicates that the instrument developers are indeed facing challenges that impact the capability to design and build quality instruments. These challenges focus on lack of resources and authority to successfully manage these instruments, lack of critical skills or expertise to implement these one-of-a-kind developments, significant problems in the area of requirements (formulation, reviews, and management), and issues with unrealistic caps, overly optimistic/unrealistic cost estimating, and externally directed changes impacting cost and schedule. The Study team recommended top-level changes in the way the Agency views and implements instrument development. The Study team also recommended improvements to key instrument development processes, such as project staffing and acquisition. The recommendations to address the Study findings should be implemented as soon as possible, with the highest level of priority. Since the NICS team only scratched the surface of problems impacting the capability to develop instruments, recommendations for continued data analysis were also provided.

Finally, the team recommends future steps to provide NASA a mechanism to work with other agencies to improve instrument development capability. To this end, the team recommends that the Agency establishes a strategic instrument capability alliance dedicated to improving the capability to design and build quality instruments within cost and schedule constraints. The alliance would provide for the following:

1. A collaborative framework for improving instrument development processes;
2. Participation from NASA, NOAA, DoD, industry, and academia;
3. Support of the implementation of Study recommendations;
4. Revision of the existing Study surveys based upon lessons learned; and
5. Development and maintenance of a tri-Agency instrument survey data repository.

A APPENDICES

A.1 OCE Kickoff Letter

National Aeronautics and Space Administration

Headquarters
Washington, DC 20546-0001

October 30, 2007

Reply to Attn of: Office of the Chief Engineer

TO: Distribution

FROM: Chief Engineer

SUBJECT: Support for the Instrument Development Capability Study

Recently, numerous NASA projects have had difficulties in developing instruments for application to their missions. In order to better understand whether a systemic instrument development issue exists, I am commissioning a study to identify core issues of NASA instrument design and development challenges. If there are indeed generic issues across aerospace industries that are causing such degradation, the study will seek options for solutions to recover such capability.

The Instrument Capability Study is being led by John Leon of the Goddard Space Flight Center (GSFC). A team is being assembled across NASA, National Oceanic and Atmospheric Administration (NOAA), Department of Defense (DoD), and industry to develop and implement the study. This study team will be surveying a cross section of personnel across many instrument developments internal and external to NASA.

In order to conduct the study and efficiently collect the information, a survey will be developed and distributed to the instrument providers at NASA Centers, other government agencies, industry, and academia. It is essential that you respond to these study questions accurately and objectively. We understand the sensitivity of this data. It is important to point out that the study findings will not be tied directly to a particular instrument and/or instrument provider. All of the information that you supply will be kept strictly confidential. In addition, the information provided will be used solely to identify potential trends across instrument providers in order to seek options for solutions to recover any degraded capability. We are hopeful that this far-reaching study will provide us with the right insight to spot trends that allow for improvement in the processes associated with instrument development. I encourage you to cooperate with the study team members and support this opportunity to contribute to the enhancement of NASA's Instrument Development Capability efforts.

Michael G. Ryschkewitsch

A.2 Study Schedule of Activities and Events

Study Initiated – August 2007
Study Team Formulation – August through September 2007
- NASA, NOAA, DoD, with support contractors providing support as requested

Study Plan Development – August through October 2007
- Designed to acquire data from instruments managers, floor level, and data mining

Survey Development – September through November 2007
- Detailed effort to acquire insight into core instrument development processes
- Reviewed and approved across multiple levels

Survey Deployment – December 2007 through March 2008
- Study team chairs ensured accurate and confidential implementation of surveys

Independent Research – September 2007 through July 2008
- Researched ~ 200 studies, reports, public media, lessons learned, etc.
- Acquired and stored ~1,000 entries into research database

Team Workshop #1 – November 15, 2007
- University of Maryland
- Survey finalized
- Data collection process discussed

Data Reconciliation, Plotting, and Analysis – February through August 2008
- Detailed effort to ensure data integrity, accurate plotting, and thorough analysis

Team Workshop #2 – March 6, 2008
- University of Maryland
- Data analysis plans finalized

Team Workshop #3 – April 22-25, 2008
- GSFC (Wallops Flight Facility, VA)
- Data analysis initialized
- ~1,000 tables and plots analyzed
- >200 rough correlations developed

Final Survey Data Received – May 2008
- 71 Instrument Survey respondents (across 41 instruments), 164 General Workforce Survey respondents

Industry Workshop – June 13, 2008
- University of Maryland
- 58 participants across government and aerospace industry
- Study and preliminary findings presented; feedback requested

Team Workshop #4 – August 11-15, 2008
- GSFC (Greenbelt, MD)
- Preliminary findings development; report draft initiated

NOAA/DoD Focus Group – August 29, 2008
- Requested feedback on preliminary findings

NASA Focus Group – September 17, 2008
- Requested feedback on preliminary findings

Final Report Developed – August through September 2008
Final Report Delivered to NASA OCE – November 2008

A.3 Acronyms and Abbreviations

APL	Applied Physics Lab
APPEL	Academy of Program/Project and Engineering Leadership
AQ	Acquisition
CDR	Critical Design Review
CDRL	Contract Data Requirements List *or* Contract Deliverables Requirements List
DoD	Department of Defense
EMI/EMC	electromagnetic interference/electromagnetic compatibility
ESMD	Exploration Systems Mission Directorate
ETU	Engineering Test Unit
EVM	Earned Value Management
FFRDC	Federally Funded Research and Development Center
GAO	Government Accountability Office
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
GWS	General Workforce Survey
HQ	Headquarters
IM	Instrument Management
IR	Independent Research
IS	Instrument Survey
ITAR	International Traffic and Arms Regulations
JHU	Johns Hopkins University
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
KDP	Key Decision Point
MIB	Mishap Investigation Board
NASA	National Aeronautics and Space Administration
NICS	NASA Instrument Capability Study
NIMS	Near Infrared Mapping Spectrometer
NOAA	National Oceanic and Atmospheric Administration
OCE	Office of the Chief Engineer
OMB	Office of Management and Budget
PDR	Preliminary Design Review
PER	Pre-Environmental Review
PI	Principal Investigator
PMIRR	Passive Modulator Infrared Radiometer
POPS	People, Organization, Project, Skills
PSR	Pre-Ship Review
RMP	Risk Management Plan
S&MA	Safety and Mission Assurance
SE	Systems Engineering
SEB	Source Evaluation Board
SMART	Specific, Measurable, Achievable, Relevant, and Traceable
SMD	Science Mission Directorate
SOMD	Space Operations Mission Directorate
SRR	Systems Requirements Review
SSO	Science Support Office
ST	Staffing
STE	Special Test Equipment

TI	Testing Issues
TMC	Technical Management and Cost
TRL	Technology Readiness Level
UIN	Unique Identification Number
UMCC	University of Maryland Conference Center
V&V	Verification and Validation
WBS	Work Breakdown Structure
XML	Extensible Markup Language

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NASA Instrument Capability Study

Final Report

December 2008

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NP-2008-11-058-GSFC